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Soil Moisture and Vegetation Patterns in Northern California Forests

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Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

Griffin, James R.

1967. **Soil moisture and vegetation patterns in northern California forests.** Berkeley, Calif., Pacific SW. Forest and Range Exp. Sta. 22 pp., illus. (U.S. Forest Serv. Res. Paper PSW-46)

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Soil Moisture and Vegetation Patterns in Northern California Forests

James R. Griffin

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The Author

JAMES R. GRIFFIN was plant ecologist on the Station's silvicultural research staff, headquartered at Redding, Calif., from 1962 to 1967. Educated at the University of California (B.S. 1952, M.S. 1958, Ph.D. 1962), he is now with the University's Hastings Natural History Reservation, Carmel Valley, Calif.

Acknowledgments

I thank the following organizations for permission to sample soils and vegetation on their lands: Kimberly-Clark Corporation, Shasta Forests Company, California Division of Forestry, Lassen National Forest, and U.S. Bureau of Land Management. Dr. Richard Waring, Forest Research Laboratory, Oregon State University, furnished many ideas for the study.

California has 3.8 million acres of commercial forest land classified as less than 10 percent stocked (Oswald and Hornibrook 1966). Much of this land supports only brush, and evaluating the productivity of such potential timber sites is next to impossible with no trees to measure. This paper reports a study seeking leads to alternative indexes of site quality. Basically, the study describes ecologically significant levels of soil moisture in a commercially important forest area with little literature in descriptive plant ecology.

Trends from a soil moisture survey are related to plant distribution and forest productivity in general terms. The usefulness of plants to indicate moisture conditions is also tested against the soil moisture data. Although the approach has wide application, specific soil-plant relationships should not be extended too far. Specific results should apply to most upland forests on basic igneous rocks between Mill Creek and the McCloud River *(fig. 1)*. In more general ways the data may be useful in the region between the Feather and Klamath Rivers *(fig. 1)*.

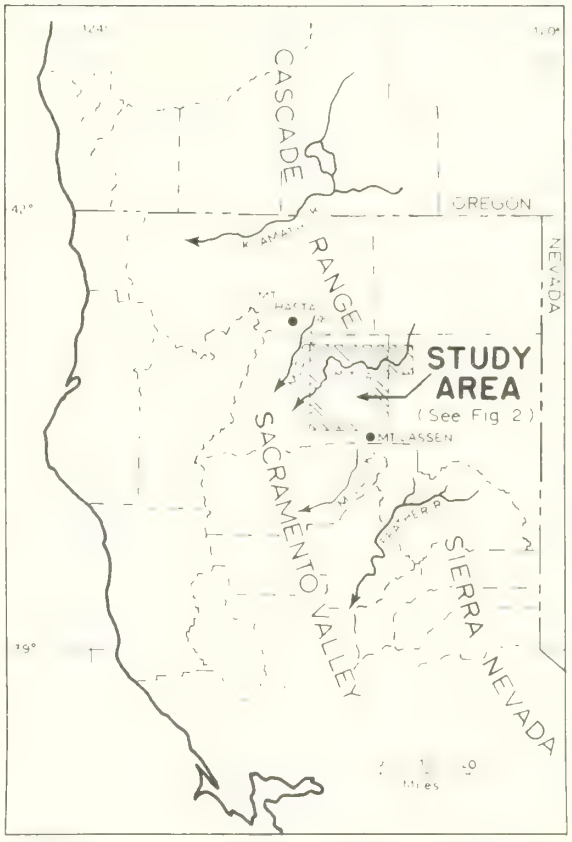

Figure 1.—*General location of the study area in northern California.*

Relevant Studies

Moisture Gradients and Plant Indicators

Whittaker (1960) described a large number of vegetation plots on several rock types in the western Siskiyou Mountains in Oregon. Many species which he discussed grow on my plots. His plots were aligned along a moisture gradient estimated from topographic position. The wettest class was assigned to deep ravines with flowing streams. The series ended with dry plots on open south and southwest slopes. Whittaker's methods help us under stand vegetational relationships over a large area. But adding direct measurement of soil moisture conditions to this sort of qualitative survey is desirable. Topographic estimates of moisture conditions are also less helpful on the gentle slopes of eastern Shasta County than in the steep Siskiyou topography.

In the California redwood region, Waring estimated the available moisture regimes in 10 vegetation types (Waring and Major 1964). These vegetation types are not closely related to those in this study, but a few species common in the redwood region do play a minor role in Shasta County vegetation.

Waring followed soil moisture depletion during two summers with gravimetric samples. After determining bulk density, rock volume, wilting point, and field capacity of the surface meter of soil, he calculated the storage capacity at each plot. He found no usable relation between total storage capacity and vegetation type. After converting his data into an available moisture index, he found that all of his upland plots had a meaningful distribution along a gradient in minimum index values.

Cleary[1] extended Waring's methods in the Oregon Cascades. His five plots along a local moisture gradient showed a high correlation between soil moisture conditions and understory vegetation. Cleary did not investigate percentages of storage capacity. Instead, he used maximum soil moisture tensions. He determined field moisture content of the 5 mm. or less fraction of 40-cm. depth samples. After developing soil moisture tension curves from the sample material, he converted field moisture contents to tensions. This aspect of his work is similar to the method independently developed in this study.

Rowe (1956) described in detail one method of deriving a moisture gradient from vegetation studies in eastern Canada. He suggested that the:

1. Method must be simple; little more than recognition of species can be expected from practical users.
2. Some insensitive species occupy a wide range of habitats. Their broad ecological distribution makes them of little value as indicators.
3. Rare plants should be used cautiously because of the danger that they are temporary invaders from outside the community.
4. The ecological distribution of very mesic species is often narrower than that of xeric species. Mesic species should be given more weight.

In practice, Rowe listed all plants in the stand under study. He deleted the most widely distributed species from the final calculations. If the total number of sensitive species dropped to about 20, he used rare species. Rowe then assigned each species to a numerical moisture group and computed an average value.

Waring has applied this type of work to California conditions (Waring and Major 1964). He called the point along a soil moisture gradient where a species' highest population density occurred the "ecological optimum." Ecological optimum data guided his assignment of species to seven moisture groups. In calculating his final index, Waring tallied the species from each group present on a study plot and averaged all the figures giving an over-all minimum available moisture index.

Waring also tested indexes weighted by population density. He stated that ". . . because frequency and relative composition of the overstory are strongly influenced by factors not related to moisture regime, the index based on species presence . . . is recommended as having the most widespread utility. In addition to being better adapted to use on cutovers and other disturbed sites, it has the added advantage of simplicity." This study is a good test of the use of a species "presence" index in disturbed sites.

Local Soil and Vegetation Work

Soil-Vegetation Surveys

Most information about forest soils and vegetation in the study area has been produced by the California Cooperative Soil-Vegetation Survey.[2] Maps like those by Mallory and Alexander (1965), Mallory *et al.* (1965a) and Mallory *et al.* (1965b) give generalized data on soil series classification, soil depth and rock content, and site quality for many of my study plots.

Most National Forest lands were not mapped in Shasta County. Mapping on private lands can be extrapolated to some plots on Federal lands. Of particular value for the higher elevation plots were the more detailed soil-vegetation maps and report for Latour State Forest (Gladish and Mallory 1964).

The California Soil-Vegetation Survey has published little interpretive material. But in a general account of California forest soils, Zinke and Colwell (1965) did use Soil-Vegetation Survey data from within the study area (near plot 15) as the volcanic rock example in a soil development discussion.

A special soil survey[3] on a small area of Shasta soil series on Mount Shasta may have some application to soil problems on some Shasta-like soils northwest of Mount Lassen.

Limited soil survey[4] information is available for the area east of the study area near Blacks Mountain.

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[1] Cleary, B. D. *A microsite study of vegetation in relation to a soil moisture gradient.* 1964. (Unpublished report on file at Oregon State University, Corvallis.)

[2] Soil-vegetation maps and legends mentioned in this paper available for purchase from the Regional Forester, U.S. Forest Service, 630 Sansome Street, San Francisco, California 94111.

[3] Conlin, B. J. *Report on soil-vegetation investigations of the Mt. Shasta brush fields tree planting project, Shasta-Trinity National Forest.* 1963. (Unpublished report on file at California Region, U.S. Forest Service, San Francisco, Calif.)

[4] Soil survey of Blacks Mountain Experiment Forest. 1940. (Unpublished map compiled by University of California soil sience students on file at Pacific Southwest Forest and Range Exp. Sta., Redding, California.)

Soil Moisture Studies

No detailed, ecologically oriented soil moisture study has been conducted in the study area. Several surveys in the past have sampled soil moisture within forest stands. For example, in the 1930's, forest entomologists tried to relate bark beetle hazard to moisture and other environmental factors. Their sampling methods and results, however, are difficult to relate to this investigation.

As part of a brush conversion project near the western end of the study area, gravimetric soil moisture samples were taken for several seasons (Adams, Ewing, and Huberty 1947; Veihmeyer and Johnson 1944). Data from their "Oregon Oaks" plot (on Aiken soil series) and "Gleason" plots (on poorly developed Cohasset soil series) showed that by mid-July the woody vegetation on undisturbed chaparral plots had removed all of the available moisture in the profile.

The most useful soil moisture study bearing on this project came from the Stanislaus-Tuolumne Experimental Forest in Tuolumne County (Fowells and Stark 1965). Although situated on granitic rocks of the central Sierra Nevada, its mixed conifer forest is closely related, ecologically and floristically, to the mixed conifer forest in Shasta County.

Soil moisture was sampled on the Experimental Forest at weekly intervals from May to October on five different plots for 8 years. Wilting points of the soil samples were established using sunflowers. Two of the plots were uncut, and their results are most applicable to this study. Moisture under a dense stand on a north aspect was above the wilting point all summer every year. Moisture in the other uncut plot on a south-facing slope dropped below the wilting point at least 1 month each summer. In the dry year of 1937 it was at or below wilting point to a depth of 101 cm.

Although the methods were relatively crude, distinctly different soil moisture regimes were documented at the Experimental Forest. The greater diversity of forest types in the larger Shasta County study area should yield sharper contrasts in soil moisture regimes.

Sampling Methods

Plot Selection

The study area lies in Shasta County near the southern end of the Cascade Range *(fig. 1)*. Thirty-seven plots within this area sampled a broad transect across the main ridge *(fig. 2)*. All important upland forest soil series were included *(table 1)*. Most data were derived from 29 "regular" plots that were studied for 3 years. This material is strengthened by eight "supplementary" plots studied for one season.

Studies of this type usually sample "undisturbed" forest stands. Measures of dominance in stable climax communities would have more statistical validity than data from disturbed habitats. Unfortunately, virgin forest is no longer available at lower elevations in Shasta County. Representative forest samples must include some young growth stands. Reasonably undisturbed stands can still be found in the mixed conifer zone, but sampling only in these spots would bias the samples toward poorer site qualities.

Selective disturbance of these forests started long ago. Over most of the mixed conifer forest, shake cutters high-graded the truly large pines in the last century. More recently, the largest pines have been selectively cut from the eastside forests because of their high insect risk.

I reduced the variation in soil forming factors between plots as much as possible by sampling only upland, volcanic soils. The mineralogical similarities in the basaltic and andesitic parent materials should have lessened the nutrient differences. Only plot 22 on the acidic rock dacite, departed from the basic igneous pattern in parent material *(table1)*.

The volcanic origin of the landscape also simplified the topographic situation. Only four plots were steep enough so that slope *per se* affected soil moisture conditions. The other plots were on level flows or on gently sloping benches along broad ridges. Lower slopes where downhill movement of water and nutrients might be a significant factor were avoided. All plots drained well. The minimal slope differences between plots strengthened the correlation between elevation and temperature.

The Soil-Vegetation Survey helped stratify the more important soils *(table 1)*. First, I sampled Aiken (clay loam/clay), Cohasset (loam/clay loam), and Windy (sandy loam) soil series. Within each

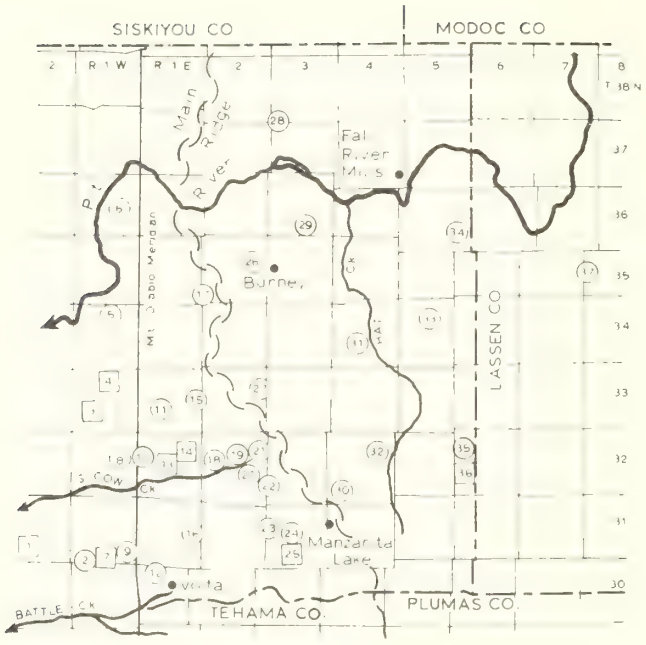

Figure 2.—*Sample plots within the study area were numbered from west to east. Plots 1 to 25 face the Sacramento Valley, and are west of the main ridge. Plots 26 to 37 are east of the ridge in the central Pit River drainage. Circles indicate the regular plots; squares, the supplementary plots.*

of these groups a broad range of site qualities was selected. Then some of the more localized soil situations were sampled for contrast with general conditions.

Moisture Sampling

Early in the project, a variety of types of soil samples were gathered. Whenever possible, I took material from the 10, 20, 40, 80, 120, 160, and 200 cm. depths. Estimates of soil depth and rock volume *(table 1)* were based on these samples. In the final moisture survey, only the 40 and 80 cm. depths were sampled.

Because of the difficulty in estimating volumes, I abandoned the use of any storage capacity method of evaluating soil moisture such as Waring had used. Instead, the samples were taken so that field soil moisture contents could be converted directly into tension figures.

Field Soil Moisture Samples

For the main survey I dug three separate pits on each sampling date. To have some control over direct vegetational effects on moisture depletion, I dug each pit in a zone of intense root activity. All pits started in litter covered soil beneath the central portion of a tree crown. Thus, even though stands of different densities and degrees of disturbance had to be used, the samples should have some comparability in evapotranspirational stress from the trees above them. No samples came from openings where root distribution might have been low.

Samples came from fixed depths as a matter of convenience. Horizon development is usually not abrupt in these soils. At a given depth, I took only one sample (5 cm. thick) per pit. Earlier experience showed that duplicate samples from the same depth in one pit often agreed within tenths of a percent or less in dry weight moisture content. In some cases there were too many rocks and insufficient time to dig all three pits to maximum depths.

The fresh material was passed quickly through a 5-mm. screen into a metal can. The entire process of removing the sample and screening it required only a few seconds. Mixing of drier soil into —or evaporation from—the sample was negligible.

The use of a 5-mm. soil fraction here departs from the traditional 2-mm. fraction, but follows the lead of McMinn (1960), Cleary,[5] and others. In rocky forest soils this coarser fraction preserves a more natural structure and rock particle content. In soils like the Aiken series, field screening to 2 mm. removes a large portion of stable aggregates. Since a coarser fraction was used, the results may not be strictly comparable with conventional data, but they may be more ecologically useful. The sample cans, which held about 100 grams of dry soil, were sealed with masking tape and weighed within 4 to 8 hours then oven-dried at 105° C. for 24 hours.

I collected the first series of moisture samples on

[5] Cleary, B. D. *Op cit.*

Table 1.--*Selected environmental characteristics at sample plots, Shasta County, California*

Plot No.	Elevation	Precipitation[1]	Parent material[2]	Soil series	Soil depth[3]	Rock volume[4]
	M.	*Cm.*			*Cm.*	*Pct.*
1	396	84	Pleist. basalt	Guenoc (Aiken-like)	75	25-50
2	563	86	Pleist. basalt	Aiken	200+	5-10
3	640	107	Plio. basalt	Aiken	100	10-15
4	762	114	Plio. basalt	Aiken	100+	5-10
5	747	165	Jura-Triois. meta-basalt	Aiken	200	0-5
6	884	173	Plio. basalt	Aiken	200+	0-5
7	663	91	Pleist. basalt	Aiken	100	10-15
8	671	102	Pleist. basalt	Aiken	100+	5-10
9	823	97	Pleist. basalt	Aiken	100+	10-15
10	747	107	Pleist. basalt	Aiken	200	0-5
11	1,097	127	Plio. basalt	Cohasset	100+	5-10
12	1,082	102	Pleist. basalt	Cohasset	200	0-5
13	838	114	Pleist. basalt	Aiken	100	10-15
14	960	127	Plio.andesite	Cohasset	200	0-5
15	1,396	152	Pleist.andesite	Cohasset	150	25-50
16	1,189	109	Pleist.basalt	McCarthy (Windy-like)	100	25-50
17	1,295	165	Plio.andesite	Windy (Cohasset)	100	25-50
18	1,067	132	Plio. tuff-breceia	Lyonsville (Cohasset-like)	200	5-10
19	1,417	140	Pleist.andesite	Cohasset	250+	25-50
20	1,859	147	Plio.andesite	Windy (Lytton-like)	100+	50-75
21	1,676	147	Plio.andesite	Cohasset	100+	25-50
22	1,798	147	Plio. dacite	Jiggs	100	25-50
23	1,341	119	Plio. basalt	Windy (Cohasset)	100+	25-50
24	1,509	127	Plio.andesite	Windy (Shasta-like)	100	25-50
25	1,509	127	Pleist.andesite	Windy	100	25-50
26	1,052	89	Plio. basalt	Cohasset	150	5-10
27	1,524	152	Pleist.basalt	Windy	100	25-50
28	1,005	97	Miocene basalt	Aiken	100+	5-10
29	968	45	Pleist.basalt	Aiken-like (Tournquist)	100+	5-10
30	1,646	112	Pleist.basalt	Windy	100	50-75
31	1,219	64	Plio. basalt	Cohasset	50+	25-50
32	1,448	81	Pleist.basalt	Windy	100	25-50
33	1,326	46	Pleist.basalt	Aiken-like (Tournquist)	100	10-20
34	1,189	41	Recent basaltic cinders	Cone-like	50+	50-75
35	1,676	64	Pleist.basalt	Windy	150+	10-20
36	1,695	71	Pleist.basalt	Windy-like	100	25-50
37	1,326	38	Plio. basalt	Wagontire (Martineck-like)	40	75-100

[1]Mean annual precipitation estimated from plate 4, Shasta County Investigation. Calif. Dep. Water Resources Bull. 22, 239 pp., illus. 1964.

[2]Geologic ages from Lydon, P. A., Gay, T. E., Jr., and Jennings, C. W.(compilers). Westwood sheet, geologic map of California. Calif. Div. Mines & Geology. 1960.

[3]Minimum depths estimated from about 15 observations per plot for the regular plots.

[4]Rock volume (>5 mm.) estimated from all plot digging experience.

the regular plots in late September 1963. Lower elevation plots were visited first. Sampling of all plots required about 2 weeks. In 1964 the regular plots were sampled in May, August, and September. In 1965, I took only a late September series.

Soil Moisture Tension Curves

Pressure plate equipment and techniques were used to determine soil moisture contents of each sample at specific soil moisture tensions. In view of the wide variations in the field, reproducibility of laboratory results offered no problems. Determined moisture contents of duplicate plot soils agreed within 1 percent both within a given pressure plate run, and between separate runs at the same tension. The only technique problem encountered during the tension work involved samples from shallow depths in Windy-like soils. They often would not "wet" unless they were completely saturated with detergent, and the results were sometimes erratic.

Soil moisture contents at the 0.3 and 15 atmosphere tensions at all depths were surveyed to estimate the range of moisture availability. The 15-atmosphere moisture contents are used as an arbitrary drought standard. I am not implying that the woody species, particularly the conifers, "wilt" when the average soil moisture tension level reaches 15 atmospheres. Different physiological processes are limited at different soil moisture tensions (Gardner and Nieman 1964).

Individual soil moisture tension curves were derived from 0.3, 1, 3, 5, 10, and 15 atmosphere data for both the 40 and 80 cm. depth samples at every plot *(fig. 3)*. Field moisture contents were converted to tension figures from these curves.

Vegetation Sampling

In 1963 I began listing recognizable plant species on the plots. The few mosses and lichens present were not identified. Floristic observations continued for 3 years. Herbarium specimens of species listed were filed at Redding. The plant names follow the usage of Munz (1959) unless authors are listed.

Quantitative study of the vegetation started in 1965. I sampled the lower elevation plots first. About 2 months were required to cover all localities, and all plots were not sampled in closely comparable seasonal stages. However, almost all known perennial species were recognized and appeared in the frequency quadrats. Details of the sampling design at a given locality are:

Unit	*Size*	*Type of Data*
one "plot"	0.81 hectare (2 acres)	list of species on plot
five "strips" within plot	total of 0.20 hectare (each 0.2 x 5 chains, 0.5 chains apart)	basal area of trees
fifty "quadrats" on centerline of strips	total of 0.02 hectare (each 1 milacre, 0.5 chains apart)	list of species on quadrats, frequency of shrubs, herbs, and tree seedlings

The d.b.h. of all living trees (over 5 cm.) were measured. In logged plots d.b.h. estimates were added for all stumps.

I took site index measurements in all plots where any trees approaching the required standards could be found. In mixed conifer stands heights of the tallest residual old-growth trees of any species were sought (Dunning 1942). In second-growth pine communities, I used dominant trees in the more even-aged groups (Arvanitis, Lindquist, and Palley 1964).

Results and Discussion

Climatic Context

Data collected by weather stations in and around study area are adequate to describe general precipitation conditions. Long-term temperature records, however, are limited. Evapotranspiration data, calculated from published temperature records, would not help in making comparisons between my plots.

Only light, widely scattered thunder showers fell during the summer of 1963 *(fig. 4)*. After this "normal" summer, field samples taken in September should have given reasonable estimates of minimum soil moisture conditions. Fall storms started just as the last samples were collected.

The winter of 1964 was relatively dry. A few late spring storms kept the growing season from starting in an exceptionally dry state. July and August were typically rainless. However, one "unseasonal" storm passed over northern California early in September *(fig. 4)*. This rain added available moisture to surface soil layers at some plots, but it probably had little effect on the 40 and 80 cm. depth samples. Again, the September samples should have given a good estimate of minimum field moisture conditions.

Growing conditions were unusually favorable in 1965. Spring rains were well timed. A series of "unseasonal" general storms over the entire region and heavy showers over the higher country added some available moisture to all plots during the summer *(fig. 4)*. This "wet" season contrasted with the two preceding summers.

Temperatures were slightly below long-term normals for most Shasta County stations during all three summers. More above normal readings occurred in 1964 than in the other two years; however, it was not a really "hot" year by local standards.

During the growing season, mean monthly temperatures may vary at least 15° F. between different plots within the transect. For example, mean

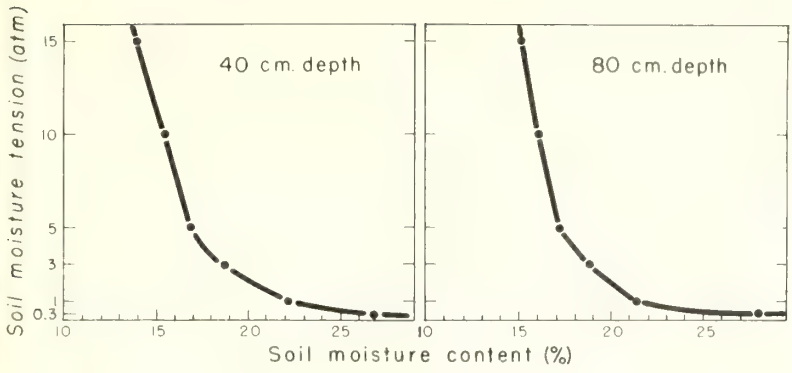

Figure 3.—*Soil moisture tension curves for the Aiken soil sample at plot 2. Similar curves were made for 40 and 80 cm. depth samples at all plots.*

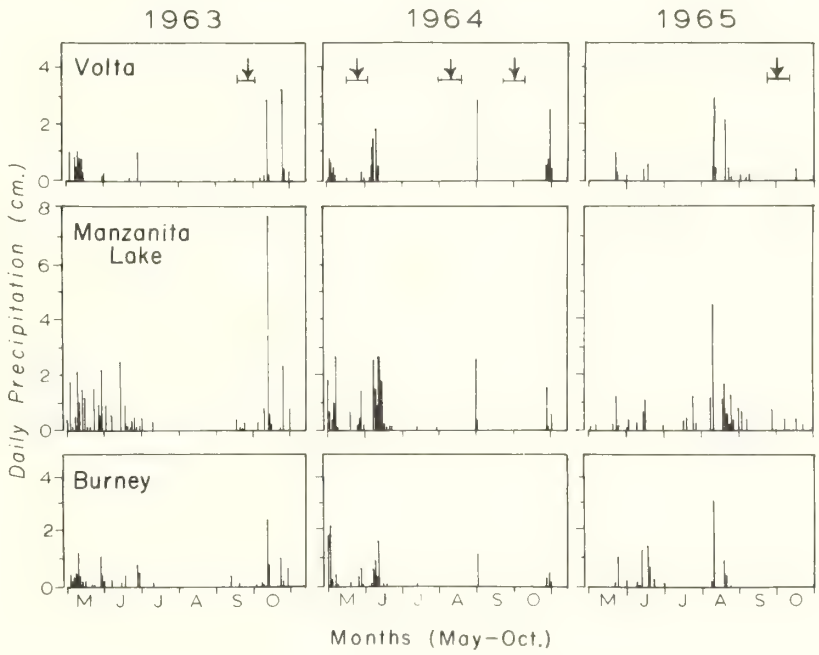

Figure 4.—*Summer rainfall patterns at three stations within the study area during the 3 years that soil moisture samples were collected. Field collection periods are indicated below the arrows. Weather station locations are shown in fig. 2.*

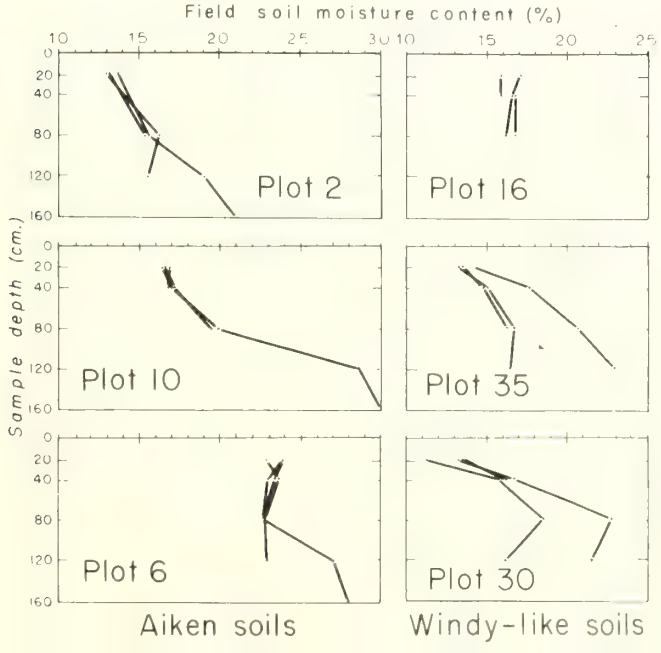

Figure 5.—*September, 1964 soil moisture content as a function of sample depth in each of three pits at three plots with deep, non-rocky, Aiken soils and three plots with rocky, Windy-like soils.*

monthly temperatures in 1964 were:

	June	July	August
		(degrees)	
Manzanita Lake	52	63	62
Volta	67	76	76

Manzanita Lake is representative of some higher elevation habitats in the central and eastern portions of the transect. A few of the higher plots may be cooler.

Volta data reflect the great evaporative stress in the lower elevation westside plots where temperatures may rise into the 90's every day for months on end. Maximum temperature at Volta in 1964 was 103° F.—only 10° below the Sacramento Valley high for the same date.

Since no pertinent temperature records were available, moisture data developed below were plotted against elevations for discussion purposes. Temperatures are related to elevation but use of elevation may obscure some broad geographic trends. For example, plots east of the main ridge have much cooler nights during the growing season. Eastside plots also have markedly lower winter minimums.

Soil Moisture Patterns

Within-Plot Variation

Variability in moisture regimes between pits on a given plot was small in deep, non-rocky soils like the Aiken series *(fig. 5)*. Replications at depths down to 80 cm. usually fell within a range of 1-percent moisture content. Greater uniformity is unlikely in California forest soils.

Deviations between the deeper Aiken samples from adjacent pits may be due to the fixed collection depths. The moist 120-cm. samples at plots 2 and 6 *(fig. 5)* came from well developed B horizons. The drier 120-cm. samples at these plots probably came from spots where the clay horizon was a little deeper than 120 cm. The differences may also be partly due to rooting patterns. The denser clay horizons may restrict root growth in places, resulting in less moisture depletion and higher moisture contents.

Rocky, Windy-like soils gave more variable results at all depths *(fig. 5)*. The 2 to 5 percent differences between samples at given depths may reflect both a real increase in soil variability and difficulty in getting comparable samples.

Better estimates of root distribution and profile development would have been desirable at some plots. A larger number of pits per plot would have been helpful in the rocky habitats. But for this type of survey, the sampling methods seem adequate to characterize soil moisture regimes on the plots for the sampling dates.

Estimating Soil Moisture Availability

Absolute moisture contents, as illustrated in *fig. 5*, have little ecological meaning when different soil textures are involved. Similar soil moisture contents can be associated with vastly different vegetation types. An Aiken sample could have more water in it at 15 atmospheres tension than a Windy sample does at 0.3 atmosphere tension.

If average field moisture contents *(fig. 5)* are placed in the context of the range of moisture availability—the range between 0.3 and 15 atmosphere moisture contents—the ecological differences between these plots becomes apparent *(fig. 6)*. For example, the Aiken, clay loam samples down to 120 cm. depth (plot 2) were near the 15 atmosphere moisture content in September. This plot then was under high drought stress. In the Windy, sandy loam sample (plot 30) (below 20 cm. depth) moisture contents were much higher than the 15 atmosphere level. This plot was under much less drought stress in September.

Ten-cm. depth samples dried out so early in the season that they had no value in comparing moisture regimes. The 20-cm. depth samples began to show differential results but still dried out quickly. The possibility that such shallow layers would be wetted by summer showers was also great. Data from the deepest samples were either incomplete or so variable that they are useful only in parts of the study area. So, I finally chose the 40- and 80-cm. depth samples to characterize moisture conditions. By using these two intermediate points I got some measure of moisture relations in the upper zones where most of the nutrients are concentrated. I also sampled the fringes of deeper zones important for storage of water late in the season.

All field moisture contents at these two depths were converted into tensions using curves similar to those in *fig. 3*. The seasonal trend during 1964 followed the expected course. May samples were near field capacity. At lower elevations the August data approached or equaled the September levels. Higher elevation plots had not reached maximum soil moisture tensions by August. Representative data comparing the maximum tensions during 3 successive years appear in *table 2*. Considering all of the sampling difficulties, the similarities in re-

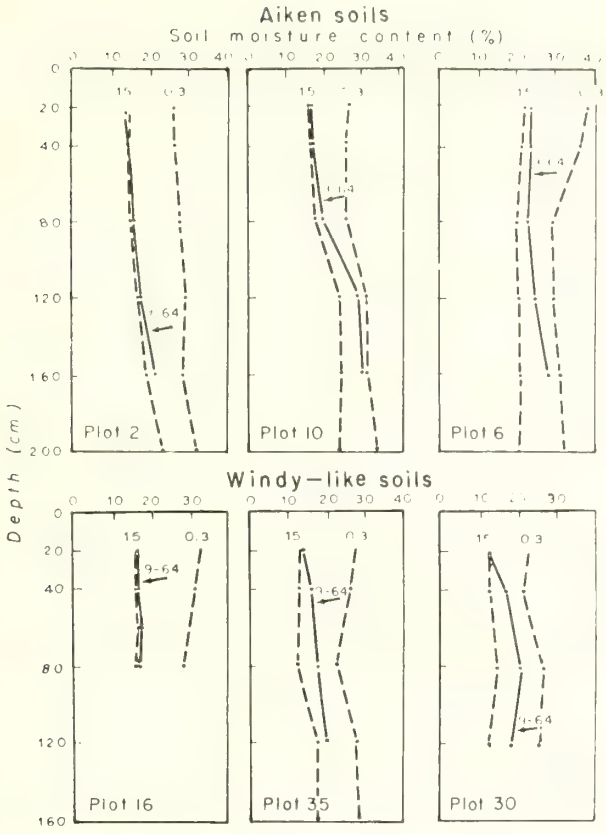

Figure 6.— *The relationship of 1964 minimum field moisture contents and the available moisture range in three representative Aiken and three Windy-like soils.*

Table 2.--*Maximum soil moisture tensions within three soil groups, sampled at two depths for 3 successive years, Shasta County, California*

Plot number	40-cm. depth			80-cm. depth		
	Sept. 1963	Sept. 1964	Sept. 1965	Sept. 1963	Sept. 1964	Sept. 1965
	Atm.			*Atm.*		
AIKEN SOILS						
2	17.0	17.0	13.0	16.0	13.0	16.0
10	8.0	11.5	7.0	1.5	3.0	10.0
28	4.0	11.0	6.0	1.0	4.0	3.5
5	7.0	7.5	8.0	4.5	3.0	4.0
6	7.0	5.0	5.0	3.0	3.0	4.0
COHASSET-LIKE SOILS						
31	17.0	13.0	17.0	10.0	7.5	15.0
11	8.5	7.5	6.0	2.5	3.5	3.0
26	7.5	7.5	7.5	4.5	1.0	4.5
19	4.5	3.5	3.5	2.0	2.0	.5
15	2.5	2.5	2.0	2.5	2.0	2.0
WINDY-LIKE SOILS						
16	10.0	12.0	12.0	8.0	10.0	15.0
35	9.5	6.0	2.5	3.0	1.5	1.5
24	3.5	3.5	2.5	1.0	2.0	2.0
20	2.0	3.5	3.5	1.0	1.0	1.0
30	1.0	2.0	1.0	.3	1.0	.5

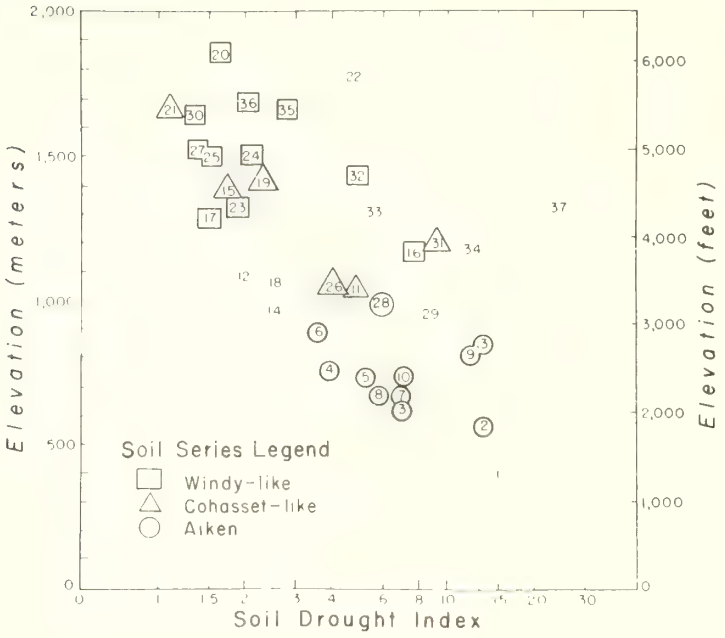

Figure 7.—*The relationships of three groups of soil series to elevation and SDI gradients. Numbers refer to the position of regular and supplementary plots, plots without symbols are not on these major series.*

Table 3.--*Four soil moisture tension values available for each regular plot and their average Soil Drought Index*

Plot number	August 1964		September 1964		Soil Drought Index
	40 cm.	80 cm.	40 cm.	80 cm.	
21	1.5	0.2	1.5	1.0	1.1
30	1.5	.5	2.0	1.0	1.3
27	1.5	.7	2.0	1.5	1.4
17	1.5	.2	3.5	.8	1.5
20	1.5	.5	3.5	1.0	1.6
15	1.5	.9	2.5	2.0	1.7
23	2.5	1.0	2.0	1.5	1.8
12	3.0	.7	3.0	1.0	1.9
24	2.5	.5	3.5	2.0	2.1
19	2.5	.8	3.5	2.0	2.2
18	2.0	.8	5.0	2.0	2.5
35	3.0	.6	6.0	1.5	2.8
6	4.0	2.0	5.0	3.5	3.6
26	7.0	.8	7.5	1.0	4.1
22	3.5	3.0	6.5	6.0	4.8
11	5.5	3.0	7.5	3.5	4.9
32	5.5	2.5	7.0	4.5	4.9
5	7.5	2.5	7.5	3.0	5.1
33	5.0	3.5	10.0	3.5	5.5
8	5.0	.8	14.5	3.0	5.8
28	7.0	1.5	11.0	4.0	5.9
10	10.5	3.0	11.5	3.0	7.0
16	4.5	4.0	12.0	10.0	7.6
31	13.0	2.5	13.0	7.5	9.0
29	10.0	2.5	15.0	8.5	9.0
9	9.0	11.0	15.0	13.0	12.0
34	6.8	8.0	20.0	14.0	12.0
2	13.0	10.0	17.0	13.0	13.3
37	25+	(1)	25+	(1)	25+

[1]Hardpan.

sults year after year at many plots are encouraging. These data generally appear to rank the plots into reasonable ecological patterns.

Soil Drought Index

Which of the tension data would best express the drought potential of all plots? The 1965 data were not used in the initial ranking of the plots because some plots may not have dried out to normal drought levels during the "wet" season. The 1963 data estimated maximum tensions but were less complete than those of 1964. Thus, the August and September data from 1964 seemed the most appropriate to use.

Combining depth and season factors into one index posed the next problem. Should 80 cm. samples be given more weight than the shallower samples that dried out more quickly? Or were September values during a semi-dormant vegetative period less important than earlier values when some plants were still actively growing?

Several schemes were tried—ranking by August data, ranking by September data, ranking by each depth, etc. All gave similar results. Finally the four tension figures from every plot were arithmetically averaged into a single Soil Drought Index *(table 3)*. This method gave a gradient that appeared ecologically meaningful. In a crude way the "average" value represents the soil moisture tension at the 60 cm. depth early in September. The physical meaning of this average should not be pushed too far; I would emphasize the *relative value* of these Soil Drought Index (SDI) numbers.

After the SDI values were established for all regular plots, tentative SDI values were estimated for the supplementary plots from all available soil moisture evidence. The discussion below is based on findings from the regular plots, but the supplementary plot data contribute to the over-all patterns and are included in some figures.

My approach gives no information on amounts of moisture at any plot. It assumes that as long as a portion of the rooting zone in one plot is at a lower average tension than that of a second plot, the plot with the lower tension is moister. For example, a large volume of soil was available to a tree on plot 2, but most of this soil was near the wilting point *(fig. 6)*. A smaller volume of soil was available to a tree on the rocky soil of plot 30; yet, some moisture was still available at the date of sampling *(fig. 6)*. The quantity of usable water in the coarse textured soil of plot 30 may be small, but in relative terms it is the moister habitat.

Each of the major soil series embraced a broad range of SDI values. When these values were plotted against elevation, however, a reasonable pattern formed *(fig. 7)*. The positions of the plots in this moisture and elevation context are consistent with the soil development trends discussed by Zinke and Colwell (1965).

The overlap of Cohasset and Windy groups may be partly due to the difficulty in digging down between the rocks to check the development of the B horizon. For example, plots 17 and 23 might be classed as Cohasset rather than Windy after closer study.

The droughty nature of the low elevation Windy-like soil (plot 16) is obvious in this type of presentation *(fig. 7)*. Morphologically this soil resembles the high elevation Windy soils. But it is located at a low enough elevation so that the high evapotranspirational stress uses up its limited storage capacity *(fig. 6)*. Interestingly, one of the few areas within the middle elevation mixed conifer forest in Shasta County where a serious brush competition problem exists is next to plot 16. There are aggressive brushfields on the Windy-like soils but few brushfields on the surrounding Cohasset soils.

In contrast, plot 24's extremely low field soil moisture contents (10 percent in September) are associated with relatively moist conditions. Although this sandy loam soil also has a small storage capacity, its cool physiographic setting keeps it from completely drying out.

Plot 22 is displaced from the Windy soil group because of the dacite parent material *(fig. 7)*. Its sandy, gravelly profile is much droughtier than Windy soils at the same elevation. The very rocky soil on recent cinders at plot 34 is also droughtier than the adjacent zonal soils. Plot 37 is an extremely unfavorable habitat for forest trees with its shallow, rocky soil over a hardpan.

Three other plots are closely related to the Aiken group *(fig. 7)*. The clay loam at plot 1 is intermediate between the Guenoc and Aiken series. Soils at the eastside plots 29 and 33 have been tentatively called Tournquist series, but they might be lumped into the Aiken series before their classification is settled.

Vegetation Patterns

Community Classification

Low elevation pine communities, middle elevation mixed conifer stands, and pure fir types at higher elevation make up the commercial forests of the Sierra Nevada. This sequence continues north-

ward from the Sierra Nevada granitic region onto the Cascade volcanic parent materials. A few gross features of this forest zonation will be considered before presenting more specific vegetation data.

Within the study area, the westside pine zone is relatively narrow. Near plots 2, 7, and 9 it extends about 6 km. through an elevational range of 450 m. *(fig. 2)*. Often the pine stands appear more as ecotones between the foothill woodland and mixed conifer forest than as important independent communities.

Well developed mixed conifer communities continue eastward above the pine zone for over 30 km. These forests usually have five major conifers and one oak species scrambled together. On gravelly benches or south facing slopes pines and oaks are conspicuous in the mixture. On higher ridges and northern aspects, firs dominate.

East of the main mixed conifer zone a mosaic of poorly developed mixed stands (on slopes) and pine stands (on flats) begins. On the Modoc Plateau these eastside pine stands become extensive, and only the higher ridges support mixed forests.

When these communities are studied only in terms of soil drought conditions, confusion results. For example, some "droughty" looking eastside pine stands have more moisture available than some well-developed mixed conifer stands. If the relative dominance of tree species is plotted against both elevation and SDI gradients, however, a better picture of this shifting forest composition emerges *(fig. 8)*. The plots fall into groups with reasonable floristic and ecological unity. I have placed these groups in the context of Munz's (1959) classification of California vegetation. The relationship of such groups to conventional forest cover types and other vegetation units is shown in *table 4*.

Most of my plots fall within the yellow pine forest community type of Munz. Since the term "yellow pine" has a confusing history of forestry uses, I prefer to change "yellow pine" to "mixed conifer forests." Subdivisions within this type, however, should be recognized. Within the Shasta County mixed conifer forest I have suggested four different dominance phases *(fig. 8)*. The boundaries between them are vague, and they represent four common conditions within a continuous array of variation. Each phase might contain several associations in phytosociological terms; in other parts

Table 4.--*Relationship between plant community types in the study area to other vegetation units*

Plant community types	Forest cover types[1]	Related vegetation units from other studies
Red fir forest[2]	Red fir (207)	Red fir forest[3]
Mixed conifer forest:		
white fir phase	White fir (211)	*Abies-Ceanothus*[4]
mixed phase	Ponderosa pine-sugar pine-fir (293) Ponderosa pine-Douglas-fir (244)	
eastside pine phase	Interior ponderosa pine (237) Jeffrey pine (247)	*Pinus-Purshia*[4] *Pinus-Purshia-Festuca*[4] *Pinus-Purshia-Arctostaphylos*[4]
westside pine phase	Pacific ponderosa pine (245) California black oak (246)	
Foothill woodland:		
savanna phase	Digger pine-oak (250)	
chaparral phase		
Northern juniper woodland	Western juniper (238)	

[1]Names and numbers refer to type descriptions (Soc. Amer. Foresters 1954).

[2]No plots actually fell within this type, which occurs on highest ridges just above the white fir phase.

[3]Oosting and Billings (1943). [4]Dyrness and Youngberg (1966).

Table 5.--*Basal area as a measure of tree species dominance along the Soil Drought Index gradient across the study area*

Species	Westside plots[1,2]																
	2	9	16	10	8	5	11	22	6	18	19	12	23	15	20	17	21
	13.3	12.0	7.6	7.0	5.8	5.1	4.9	4.8	3.6	2.5	2.2	1.9	1.8	1.7	1.6	1.5	1.1
	Square m./hectare																
Pinus monticola	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(4)
Abies magnifica	--	--	--	--	--	--	--	1.1	--	--	--	--	--	--	--	--	(4/)
Abies concolor	--	--	3.0	(4)	--	2.6	6.4	5.7	4.1	2.3	14.2	3.7	54.9	10.8	5.7	25.3	76.9
Pinus lambertiana	--	--	(4)	(4)	--	(4)	5.7	4.6	(4)	--	13.1	(4)	8.7	34.0	(4)	3.2	20.9
Pseudotsuga menziesii	--	--	(4)	(4)	--	15.8	8.3	--	8.3	1.5	16.8	(4)	12.6	2.1	--	23.4	(4)
Libocedrus decurrens	--	--	7.8	20.7	3.7	12.9	10.3	--	7.3	13.1	10.2	18.8	7.3	22.3	.2	8.7	.2
Pinus ponderosa	(4)	2.3	3.7	34.4	14.0	7.3	19.1	--	8.9	3.2	14.2	14.2	(4)	1.6	--	.7	3.4
Quercus kelloggii	11.7	15.8	7.3	11.5	11.0	9.2	2.3	--	6.0	3.0	1.1	5.7	.9	.7	.5	.9	--
Quercus garryana	--	10.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pinus jeffreyi	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.4	--	3.4
Pinus sabiniana	2.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Juniperus occidentalis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	14.2	28.9	21.8	66.6	28.7	47.8	52.1	11.9	34.6	33.1	70.0	42.4	84.4	71.5	9.8	62.2	104.8

	Eastside plots[1,3]										
	30	27	35	26	32	33	28	31	29	34	37
	1.3	1.4	2.8	4.1	4.9	5.5	5.9	9.0	9.0	12.0	25+
	Square m. hectare										
Pinus monticola	--	--	--	--	--	--	--	--	--	--	--
Abies magnifica	--	--	--	--	--	--	--	--	--	--	--
Abies concolor	49.1	24.8	(4)	1.1	(4/)	--	--	1.4	--	--	--
Pinus lambertiana	--	(4)	--	(4)	--	--	(4)	3.0	(4)	--	--
Pseudotsuga menziesii	--	--	--	6.7	--	--	7.3	.5	--	--	--
Libocedrus decurrens	--	.2	--	16.5	--	--	6.9	7.1	--	--	--
Pinus ponderosa	--	27.6	34.7	14.5	6.0	17.4	23.9	11.5	17.2	13.5	--
Quercus kelloggii	--	--	--	13.4	--	--	1.4	2.1	2.3	--	--
Quercus garryana	--	--	--	--	--	--	--	--	5.3	--	--
Pinus jeffreyi	24.3	--	8.5	(4)	30.3	(4)	--	--	--	.7	1.1
Pinus sabiniana	--	--	--	--	--	--	--	--	--	--	--
Juniperus occidentalis	--	--	--	--	--	1.8	--	--	--	--	6.4
Total	73.4	52.6	43.2	52.2	36.3	19.7	39.5	25.6	24.8	14.2	7.5

[1]All regular plots listed except number 24 which is in a brushfield and had no tree basal area.
[2]Plots ranked along decreasing drought stress up the west slope of the Cascade ridge. SDI listed under each plot number.
[3]Plots ranked along increasing drought stress up the east slope of the Cascade ridge. SDI listed under each plot number.
[4]Species present on plot but had less than 0.1 $m.^2$ h. on cruise strips.

of California, additional phases might be necessary.

Figure 8 is helpful in showing the central position of the mixed conifer forest in Sierra-Cascade forest vegetation. It also reveals the interrelationships of the four phases within the local mixed conifer forest.

In other regions it might be better to emphasize the separateness of the pine types from the mixed type. Whittaker viewed his pine woodlands and montane forest as distinct formations. I would like to stress their intermediate character—westside pine stands joining the foothill woodland to the mixed conifer forest, and eastside pine stands merging the juniper woodland to the mixed conifer forest *(fig. 8)*.

In Shasta County the westside and eastside forests are less isolated geographically than along most of the Sierra Nevada-Cascade axis (Griffin 1966). Plots along the Pit River canyon and lower portions of the Burney basin would yield a series of intermediate environments and intermediate vegetation types. The manner in which the two pine phases fit around the mixed phase reflects this situation *(fig. 8)*.

Relative Tree Dominance

All plots in the central portion of the transect now clearly have mixed conifer stands *(table 5)*. The tree reproduction data suggest that this condition will continue although the proportion of different species may change. Thus, *Libocedrus decurrens* comprised about one third of the basal area in plot 31, but it has well established reproduction on some 90 percent of the area. *Libocedrus* will be more important in the next stand.

For practical purposes, the westside pine stands are climax communities. Successional trends toward mixed conditions, however, are not hard to find in sheltered spots. Thus, plot 10 at only 747 m. elevation is just above the foothill woodland. Yet, all of the mixed conifer species have a couple of saplings established *(table 5)*.

Plot 30 illustrates the upper end of this sequence where the trend is toward pure fir stands. Although it has one third of its basal area in *Pinus jeffereyi* now, the pine will become a minor component in the fir stand with time.

Plots 32 and 35 both show the tendency for many eastside pine stands to have a sprinkling of understory firs.

All of the overstory tree species had broad tolerances to moisture conditions. *Pinus ponderosa* and *Quercus kelloggii* are good example *(fig. 9)*. They both formed larger percentages of the stand on drier plots but had no sharp moisture preferences. *Abies concolor* showed a greater dominance on moister plots *(fig. 9)*.

Pinus jeffreyi managed to grow on both the wettest and driest plots. Although my sampling is too limited to be conclusive, *P. jeffreyi* appears to have a bimodal distribution *(fig. 9)*. It grows on dry, eastside flats and on moist, higher slopes on both sides of the main ridge. These two kinds of *P. jeffreyi* habitats are usually separated by a distinct zone of mixed conifer forest.

Theoretically, physiological ecotypes are to be expected within such widely distributed tree species. Unfortunately, there is no convenient way to recognize them. No obvious morphological differences are revealed as they grow in the field.

Few understory trees appear on the plots, and none contributed to the basal area data. Small *Cornus nuttallii* trees were present on seven plots. *Taxus brevifolia* and *Acer circinatum* were the only trees with conspicuously narrow moisture tolerances. In Shasta County they are largely riparian species and grow only sparingly on uplands. *Taxus* was present on plots 17 and 18. Only plot 17 had the maple. If I had included higher elevation stands north of the Pit River in the transect, these understory trees would have assumed greater importance.

Quercus chrysolepis played a minor role in the understory. On steep, rocky slopes large trees form an important part of the forest, often in company with *Pseudotsuga menziesii* (see type 249, Soc. Amer. Foresters 1954). On the study plots *Q. chrysolepis* appeared only as scattered shrubs or small trees.

Site Quality

Neither the vegetation units outlined above nor their related site quality classes coincide very well with any soil series. Most of the fir stands are on Windy-like soils; yet, these soils include some of the highest quality mixed conifer stands as well as extensive non-timbered high elevation brushfields. There may be a better correspondence of mixed conifer stands with Cohasset soils. Most of the westside pine stands are on Aiken soils, but these soils stretch from the upper fringes of non-commercial foothill woodland to productive mixed conifer stands.

This range of variation in vegetation types and site qualities within the Aiken soil series is shown in greater detail in *table 6*. Although there are difficulties in finding appropriate site measurement

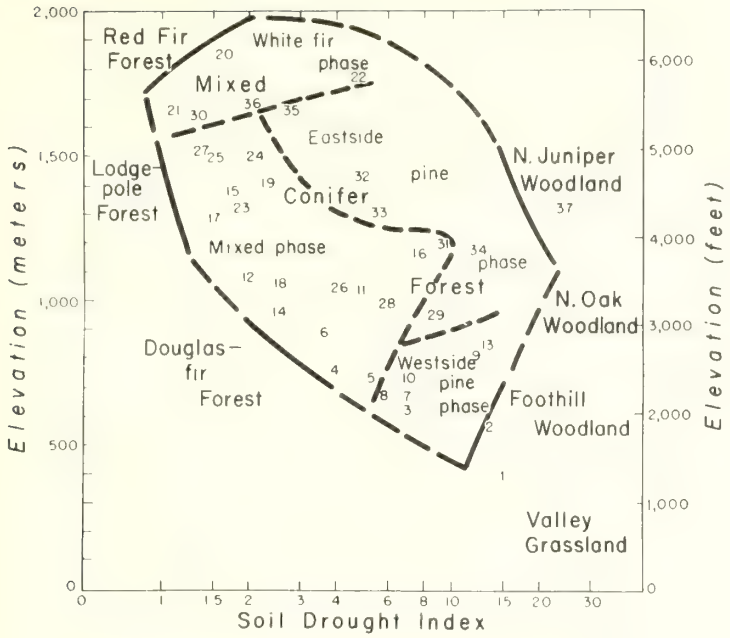

Figure 8.—*The relationship of plant community types (Munz 1959) to elevation and SDI gradients. Numbers refer to positions of regular and supplementary plots.*

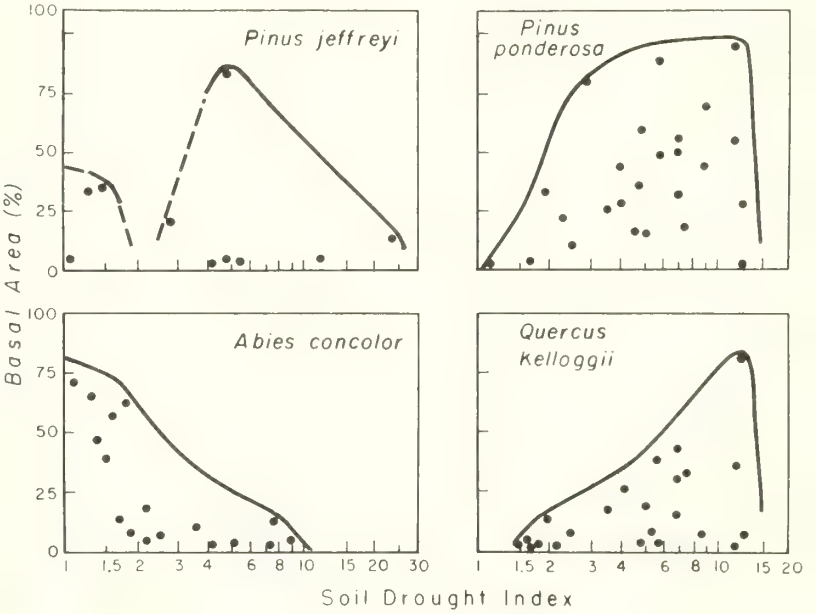

Figure 9. —*Relative dominance (basal area of given species as a percentage of total basal area on plot) of selected trees species along the SDI gradient. Numbers refer to positions of individual plots.*

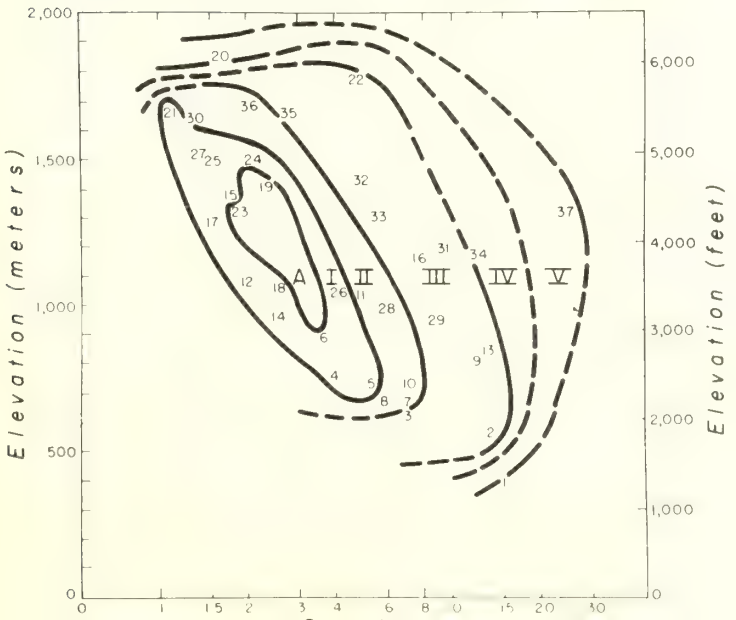

Figure 10.—*Relationship of site quality to elevation and SDI gradients. Roman numerals (and A) refer to site quality classes (Dunning 1942) estimated from field observations and S-V Survey data. Numbers refer to plot positions.*

Table 6.--*Variation in vegetation type, site quality, tree basal area, and Soil Drought Index within the Aiken soil series plots*[1]

Plant community type	Site index[2]	Total tree basal area	Soil Drought Index[3]
		Square m./ hectare	
Foothill woodland:			
Chaparral phase			
Plot 2	[4]/ 85	14.2	13.3
Mixed conifer forest:			
Westside pine phase			
Plot 8	90	28.7	5.8
Plot 13	90	27.3	13.0
Plot 9	95	28.9	12.0
Plot 10	95	66.6	7.0
Plot 7	100	24.9	7.0
Plot 3	100	27.6	7.0
Mixed phase			
Plot 28	90	39.5	5.9
Plot 5	115+	47.8	5.1
Plot 4	115+	41.5	4.0
Plot 6	130+	34.9	3.6

[1]All plots listed were within areas mapped by Soil-Vegetation Survey as Aiken soil series.

[2]Arvanitis et al. 1964.

[3]Soil Drought Index values for the supplementary plots (3, 4, 7, 13) were estimated from all available soil moisture data.

[4]No pines available for site measurement on the plot--figure was taken from closest available stand 1 km. away.

trees, the site index figures seem to be more sensitive to changes in productivity than the basal area data. A much larger basal area sample would be needed to overcome the effects of past fires and disturbance on basal areas at some plots.

When the plots are aligned along a gradient in site index, only one SDI value (plot 8) is clearly out of line *(table 6)*. This plot had a very dense clay horizon in places, and poor root distribution may have caused less moisture depletion—and thus lower SDI values—than expected in the soil samples.

Site quality estimates for all the plots make an interesting pattern of concentric zones when plotted against elevation and SDI values *(fig. 10)*. The greatest sustained height growth seemed to occur in mesic mixed conifer stands between the 1,000 and 1,500 m. elevation. Early height growth may be more rapid in some lower elevation pine stands, but they do not produce such large trees at maturity. Some fir stands at higher elevations accumulated greater volumes of wood per unit area at maturity than the mixed forests.

Brush Characteristics

The lower elevation ends of the transect had the greatest diversity of shrub species *(table 7)*. Plot 2 supported at least 18 shrubby species while plot 34 had 17 species. On the lower fringe of the westside pine zone some of the chaparral shrubs reached impressive size. Both *Arctostaphylos manzanita* and *A. viscida* approached 9 m. in height in favorable spots. One *A. manzanita* bush on plot 2 was 7.9 m. tall; another on plot 8 had a short trunk 68 cm. in diameter. Although such individual shrubs are massive, repeated disturbance seems necessary to convert the pine and oak communities to "chaparral."

The high-elevation brushfields have the highest density of shrubs. To cross some of these stands you must literally walk on top of the brush. Portions of the rockier and more exposed brushfields are clearly climax in nature. Other parts of these brushfields were mixed conifer or fir forest and have become brushfields through severe burning.

Like the trees, many shrub species tolerate a broad range of moisture conditions. *Amelanchier pallida,* for example *(table 7)*, grows under almost as great a range of conditions as does *Pinus jeffreyi*. The form of *Amelanchier,* however, changes in the different habitats. In mesic mixed conifer stands (plot 17) it grows almost as a small tree while in the juniper woodland (plot 37) it is semiprostrate. In contrast, *Rubus parviflorus* exhibits a

narrow ecological range *(table 7)*. It grows in canyon bottoms and creek beds as a shrub, but on the plots only very small shrubs appear on the moister spots.

Species like *Prunus subcordata* and *Rhamnus rubra* are widely distributed in the westside forests as large shrubs. On the eastside they often form small, compact, almost spinose shrubs. Some of these eastside forms correspond roughly to formally described taxa, for example *Rhamnus rubra* ssp. *modocensis*. The heavy deer browse pressure on the eastside plots may contribute to this "eastside growth habit."

Some chaparral species which appear locally in the westside pine stands reappear east of the ridge (Griffin 1966). *Cercocarpus betuloides, Ceanothus cuneatus,* and *Rhus trilobata* illustrate this pattern on the plots *(table 7)*. The SDI data suggest that the moisture availability on the two ends of the transect may be similar despite the large difference in total precipitation. Some foothill woodland stands may receive more than three times

Table 7.--*Frequency of common shrubs along the Soil Drought Index gradient across the study area, by species*

Species	Westside plots[1]																	
	2	9	16	10	8	5	11	22	6	18	19	24	12	23	15	20	17	21
	13.3	12.0	7.6	7.0	5.8	5.1	4.9	4.8	3.6	2.5	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.1
	Frequency percent																	
Ceanothus velutinus	--	--	--	--	--	--	--	39	--	--	--	81	--	--	--	56	--	--
Castanopsis sempervirens	--	--	--	--	--	--	--	90	--	--	4	45	--	(2/)	(3/)	96	6	18
Prunus emarginata	--	--	--	--	--	--	--	7	--	--	--	78	--	--	--	16	--	--
Rubus parviflorus	--	--	--	--	--	--	--	--	(3/)	--	(3/)	--	--	10	(3/)	--	18	--
Paxistima myrsinites	--	--	--	--	--	--	--	--	8	--	--	--	--	--	2	--	18	--
Ribes roezlii	--	--	--	--	--	(3/)	(3/)	--	--	2	2	--	(3/)	4	10	(3)	6	--
Rosa gymnocarpa	--	--	--	--	--	6	--	--	10	--	(3/)	--	--	10	8	--	12	--
Symphoricarpos acutus	--	--	4	(3/)	--	(3/)	4	6	70	(3)	--	--	8	14	52	20	30	2
Amelanchier pallida	--	--	--	--	--	--	--	--	(3/)	--	--	--	--	--	6	52	2	10
Arctostaphylos viscida	27	56	2	48	82	2	(3/)	--	--	--	--	--	4	--	--	--	--	--
Arctostaphylos manzanita	33	42	--	20	38	--	6	--	2	--	--	--	6	--	--	--	--	--
Arctostaphylos patula	--	--	44	--	--	--	--	--	--	--	--	100	--	--	--	--	--	--
Purshia tridentata	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--
Artemisia tridentata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cercocarpus ledifolius	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cercocarpus betuloides	(3/)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus trilobata	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lonicera interrupta	3	--	--	(3)	(3)	--	--	--	--	--	--	--	--	--	--	--	--	--
Rhus diversiloba	51	30	--	22	8	16	--	--	--	--	--	--	--	--	--	--	--	--
Ceanothus cuneatus	(3)	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

	Eastside plots[2]										
	30	27	35	26	32	33	28	31	29	34	37
	1.3	1.4	2.8	4.1	4.9	5.5	5.9	9.0	9.0	12.0	25+
	Frequency percent										
Ceanothus velutinus	(3/)	(3)	--	--	--	--	—	--	--	--	--
Castanopsis sempervirens	(3/)	--	--	--	--	--	--	--	--	--	--
Prunus emarginata	--	--	--	--	--	--	--	--	--	--	--
Rubus parviflorus	--	--	--	--	--	--	--	--	--	--	--
Paxistima myrsinites	--	--	-	--	--	--	--	--	--	--	--
Ribes roezlii	(3/)	(3)	--	(3)	--	--	--	--	--	—	--
Rosa gymnocarpa	--	--	--	--	--	--	--	--	--	--	--
Symphoricarpos acutus	--	65	(3)	--	--	--	--	6	—	—	--
Amelanchier pallida	2	50	--	(3)	--	2	4	--	4	(3)	(3/)
Arctostaphylos viscida	--	--	--	--	--	--	--	--	--	--	--
Arctostaphylos manzanita	--	--	--	--	--	--	--	--	--	--	--
Arctostaphylos patula	—	(3/)	20	26	54	2	(3)	12	12	10	(3)
Purshia tridentata	--	--	50	—	10	10	--	--	50	64	52
Artemisia tridentata	--	--	68	--	2	4	--	--	--	--	36
Cercocarpus ledifolius	--	--	(3)	—	--	28	--	(3)	--	4	12
Cercocarpus betuloides	--	--	--	-	--	4	2	10	4	8	12
Rhus trilobata	—	--	--	—	--	2	--	—	8	2	(3/)
Lonicera interrupta	--	--	--	--	--	(3/)	—	--	--	2	(3)
Rhus diversiloba	--	--	--	—	—	--	--	--	--	--	--
Ceanothus cuneatus	—	--	--	--	--	--	--	--	--	(3)	--

[1]Plots ranked along decreasing drought stress up the west slope of the Cascade ridge, SDI listed under each plot number.
[2]Plots ranked along increasing drought stress down the east slope of the Cascade ridge, SDI listed under each plot number.
[3]Species present on plot but not on frequency quadrats.

as much precipitation as the juniper woodland stands, yet these woodland communities are both under comparable drought stress by early summer.

Several forms of *Arctostaphylos* in this region are not satisfactorily treated in the taxonomic literature (Gladish and Mallory 1964; Mallory *et al.* 1965b). A summary of the local manzanita situation in Shasta County in the context of elevation and SDI gradients is given as an example of the usefulness of this index *(fig. 11)*.

Arctostaphylos manzanita has two forms, a non-glandular, non-sprouting type at lower elevations;

Table 8.--*Species used to calculate Vegetation Drought Index (VDI)*[1] *values for plots representative of three different vegetation types,*[1] *Shasta County, California, by tentative vegetation drought groups*[2]

Tentative vegetation drought groups	Plot No. 9 (westside pine phase)	Total group values[3]	Plot No. 17 (mixed phase)	Total group values[3]	Plot No. 34 (eastside pine phase)	Total group values[3]
I	--		*Acer circinatum*		--	
	--		*Rubus parviflorus*		--	
	--	--	*Taxus brevifolia*	3 X 1 = 3	--	--
II	--		*Castanopsis sempervirens*		--	
	--	--	*Smilacina racemosa*	2 X 2 = 4	--	--
III	--		*Abies concolor*		--	
	--		*Adenocaulon bicolor*		--	
	--		*Chimaphila menziesii*		--	
	--		*Corallorhiza striata*		--	
	--		*Cornus nuttallii*		--	
	--		*Disporum hookeri*		--	
	--		*Galium triflorum*		--	
	--		*Paxistima myrsinites*		--	
	--	--	*Pyrola picta*	9 X 3 = 27	--	--
IV	*Ceanothus integerrimus*		*Berberis piperiana*		*Ceanothus integerrimus*	
	--		*Campanula prenanthoides*		--	
	--		*Carex rossii*		--	
	--		*Chimaphila umbellata*		--	
	--		*Festuca occidentalis*		--	
	--		*Goodyera oblongifolia*		--	
	--		*Pinus lambertiana*		--	
	--		*Pterospora andromedea*		--	
	--		*Pseudotsuga menziesii*		--	
	--		*Ribes roezlii*		--	
	--		*Rosa gymnocarpa*		--	
	--		*Trientalis latifolia*		--	
	--		*Trisetum cernuum*		--	
	--	1 X 4 = 4	*Symphoricarpos acutus*	14 X 4 = 56	--	1 X 4 = 4
V	*Bromus orcuttianus*		*Asarum hartwegii*		*Arctostaphylos patula*	
	Ceanothus prostratus		*Bromus orcuttianus*		*Festuca idahoensis*	
	Hieracium albiflorum		*Hieracium albiflorum*		*Haplopappus bloomeri*	
	Horkelia tridentata		*Iris tenuissima*		*Libocedrus decurrens*	
	Iris tenuissima		*Libocedrus decurrens*		*Pinus ponderosa*	
	Libocedrus decurrens		*Melica aristata*		*Sitanion hystrix*	
	Pinus ponderosa		*Pinus ponderosa*		--	
	Polygala cornuta		*Polygala cornuta*		--	
	Sitanion hystrix		*Pteridium aquilinum*		--	
	Viola lobata		*Pyrola aphylla*		--	
	--	10 X 5 = 50	*Viola lobata*	11 X 5 = 55	--	6 X 5 = 30
VI	*Arctostaphylos manzan.*		*Carex multicaulis*		*Castilleja applegatei*	
	Arctostaphylos viscida		*Galium bolanderi*		*Clarkia rhomboidea*	
	Calochortus tolmiei		*Quercus kelloggii*		*Collomia grandiflora*	
	Carex multicaulis		--		*Galium bolanderi*	
	Clarkia rhomboidea		--		*Lupinus caudatus*	
	Comandra pallida		--		*Poa sandbergii*	
	Dentaria californica		--		*Prunus subcordata*	
	Galium bolanderi		--		*Quercus garryana*	
	Lathyrus sulphureus		--		*Quercus kelloggii*	
	Lupinus adsurgens		--		*Rhus triloba*	
	Pedicularis densiflora		--		*Senecio aronicoides*	
	Quercus kelloggii		--		*Wyethia mollis*	
	Sanicula bipinnatifida		--		--	
	Senecio aronicoides		--		--	
	Stipa lemmonii	15 X 6 = 90	--	3 X 6 = 18	--	12 X 6 = 72
VII	*Agosera retrosa*		--		*Arabis holboellii*	
	Brodiaea multiflora		--		*Ceanothus cuneatus*	
	Ceanothus cuneatus		--		*Cercis occidentalis*	
	Ceanothus lemmonii		--		*Cercocarpus betuloides*	
	Dodocatheon hendersonii		--		*Cercocarpus ledifolius*	
	Lonicera interrupta		--		*Collinsia parviflora*	
	Ranunculus occidentalis		--		*Eriophyllum lantanum*	
	Rhamnus californica		--		*Juniperus occidentalis*	
	Rhus diversiloba		--		*Leptodactylon pungens*	
	--		--		*Lonicera interrupta*	
	--		--		*Purshia tridentata*	
	--	9 X 7 = 63	--	--	*Stipa thurberiana*	12 X 7 = 84
VIII	--		--		*Bromus tectorum*	
	--	--	--	--	*Penstemon deustus*	2 X 8 = 16
Vegetation Drought Index		207/35 = 5.9		163/42 = 3.9		206/33 = 6.2

[1]Vegetation Drought Index equals Total group values/Total species.

[2]Less sensitive and rare species were excluded.

[3]Number of species X value assigned to Vegetation Drought Group.

and a glandular, weakly sprouting type at higher elevations. *A. "patula"* has two forms, one a burl forming, sprouting type common on the eastside but only local on the westside. I have called the non-sprouting, non-burl forming type *A. obtusifolia* Piper (Hayes and Garrison 1960). It is called *A. parryana* var. *pinetorum* by the Soil-Vegetation Survey.

The ecological relationships apparent in this sort of graph may help in studying the confusing genetic relationships of these species. Other genera like *Ceanothus* or *Rhamnus* which have many species in the study area would present somewhat similar patterns.

Herbaceous Flora

Such a large number of herbaceous species occurred on the plots—about 200—that the complete presence and frequency data for them cannot be conveniently listed. Remarks about some herbs are made in the following section on plant indicators, and many herbs are included in the species lists for the representative westside pine, mixed, and eastside pine stands given in *table 8*. More detailed treatment of the herbaceous data, as well as additional notes on trees and shrubs, will be published separately.

Plant Indicator Applications

Assigning Vegetation Drought Values

Using SDI and vegetation dominance data, I assigned as many species as possible to one of eight vegetation drought groups *(fig. 12)*. The position of a species' ecological optimum along the SDI gradient helped in this task. It wasn't practical to make the vegetation drought units equal to the SDI units. Also to avoid confusion between the numerical value of the vegetation and soil units, the vegetation drought figures are shown as Roman numerals in this discussion.

For this preliminary effort, the logarithmic SDI scale was divided into five approximately equal units. Three additional units covered species present on the plots but having ecological optimums outside the study area. Thus, group I included the typically riparian species which had a few individuals on the mesic plots. Group II included species which were important in the higher fir forests and brushfields. On the other end of the scale group VIII included xeric species typical of grassy habitats below the study area *(fig. 12)*.

When the peak of the frequency curve suggested a clear ecological optimum it was used. For example *Chimaphila menziesii* corresponds roughly to group III *(fig. 12)*. For species with ecological tolerances broad enough to cover several groups, the central value was chosen. If the ecological trend was less clear from the plot data, personal experience and the literature helped to make the decision. No assignments were made for the rare species. Plants like *Fritillaria atropurpurea, Lathyrus tracyi,* or *Lotus grandiflorus* might be helpful indicators if more were known about their local ecological behavior.

The widely distributed shrubs like *Amelanchier pallida* and *Rhamnus rubra* could not be used. They might include unrecognizable physiological ecotypes that would each have different indicator values. Some herbs could not be used for the same reason. Thus, *Viola purpurea* should have had three or four physiologically distinct subspecies in different habitats along the transect. Unfortunately, they could be readily distinguished only by the habitats and not by their morphology. The most weedy herbs like *Cryptantha affinis* also were not used.

Vegetation Drought Index

After assigning drought values to all species with any indicator potential, I calculated a Vegetation Drought Index (VDI) for each plot. Since the logging disturbance on many plots had altered density patterns, I followed Waring's suggestion and did not weight the species data by any density factor. The number and vigor of individual plants influenced the assignment of drought values for each species, but only the presence or absence of a species entered into the calculation of plot VDI. If the species was present, its drought value was added to the plot total.

I tried two methods of calculating the VDI for each locality. First, drought values from the species list for the quadrats were averaged. Then to increase the number of species per sample locality, I used the species list for the entire plot—in effect enlarging the sample size. Both results were similar. Thirteen localities had identical averages by either method. The "plot" average, in which the less common plants had a greater influence, seemed to give a little better ranking than the "quadrat" average. Calculation of VDI for three different plots is illustrated *(table 8)*.

One problem anticipated in the use of these methods in the Sierra Nevada vegetation types was

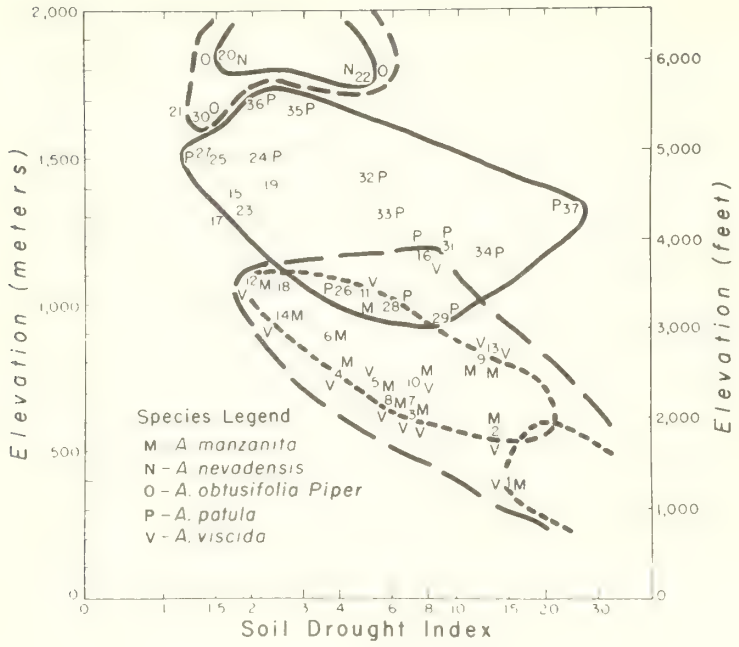

Figure 11.—*Distribution of* Arctostaphylos *species in the study area along elevation and SDI gradients. Numbers indicate plot positions and letters the species present at given plots.*

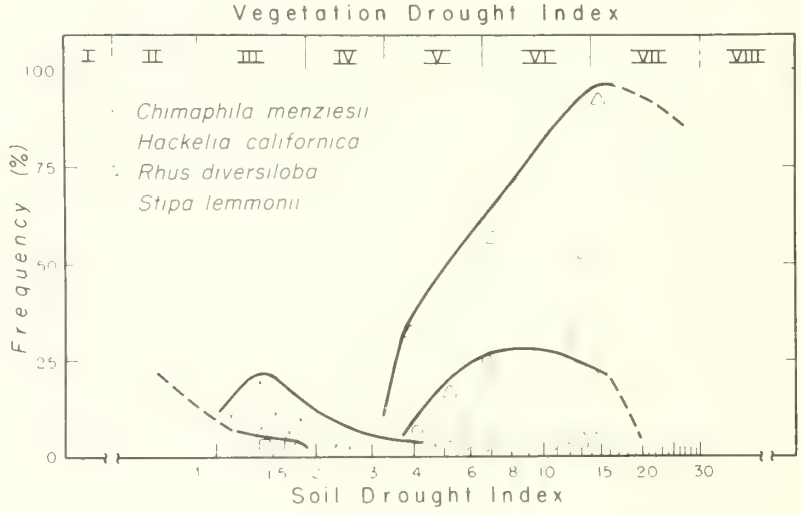

Figure 12.—*Examples of how species were assigned to vegetation drought groups prior to the calculation of the Vegetation Drought Index (VDI).*

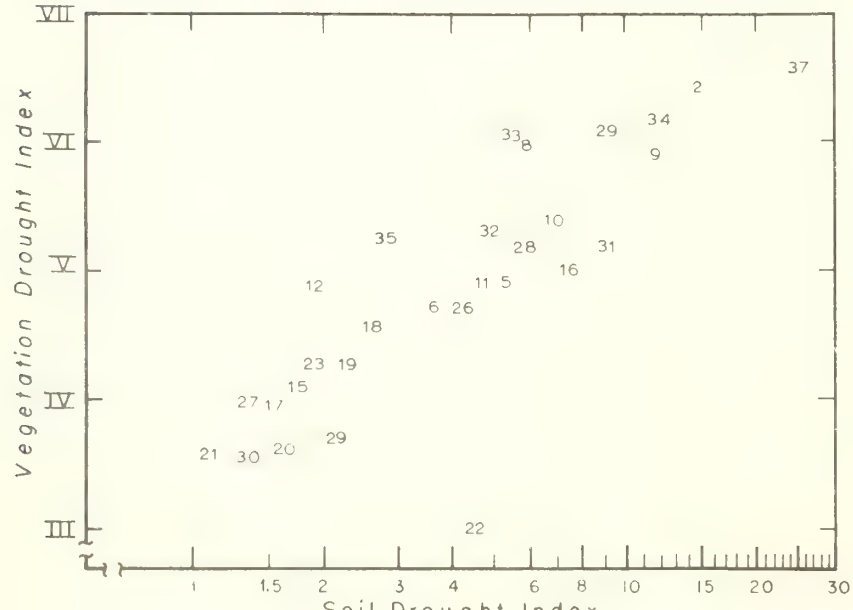

Figure 13.—*Relationship between SDI and VDI values. Numbers indicate regular plot positions.*

the limited number of species that would be present in some communities. A small number of species is undesirable because of the large influence that any one species can have on the plot average. Rowe (1956) wanted at least 25 indicator species per plot.

This problem did arise, because eight "plots" had less than 25 usable species present. In the "quadrat" lists, nearly half the sample localities had less than 25 species. In higher elevation fir stands this problem would have been acute.

Comparing Soil and Vegetation Drought Indexes

Plot ranking by the VDI is similar to that given by the SDI *(fig. 13)*. Only plot 22 is grossly out of line *(fig. 13)*. Its VDI is much lower than would be expected from the soil moisture data. The VDI might be questioned in this case because of the small number of species present—only 17 on the entire plot.

Plot 22 has a very coarse textured profile. Although the soil is droughty in relation to adjacent zonal soils, the cold climate at the higher elevation of this plot may exclude some of the "droughty" plant indicators that appear at lower elevation.

In some cases the VDI appears to be a better estimate of field moisture conditions than SDI. Intuitively, I would rate plot 8 more xeric than plot 10. The SDI does not support this view, but the VDI does. Poor root penetration into the clay samples at plot 8 may have influenced the low SDI values.

On the whole, the SDI seemed to give a satisfactory measure of soil moisture conditions. Weaknesses in the VDI probably contributed more to the scatter of points in *fig. 8* than problems with the SDI. The convenience of the VDI methods, however, justifies more work with this approach. With more refined drought value assignments to the common indicator species, VDI methods might rank pine and mixed conifer plots along moisture gradients far better than any intuitive system.

Summary and Conclusions

The soil drought index shows promise as a way of describing soil moisture conditions on forest plots. It is not appropriate for surveying amounts of soil water, but is well suited for ranking plots along a gradient of soil moisture availability. For more intensive studies, the slow gravimetric sampling used to follow moisture depletion might be changed to an indirect method. Establishing soil moisture tension curves with the same material that depletion is measured in, however, seems essential. The mechanics of sampling in rocky soil limits the use of this approach, but with adequate sample size, the resulting index does give an ecologically meaningful measure of soil moisture. If this sort of soil moisture stress approach is not adequate, the next step could be to move from the soil into the plants themselves and estimate their internal moisture stress.

The soil moisture results in this study support the conclusions of Fowells and Stark (1965). Soil moisture is not always severely limiting in mixed conifer communities. Except for the surface layer, only in the drier habitats during drier seasons does the average soil moisture tension exceed 15 atmospheres. If competing vegetation were reduced, the lack of soil moisture should not be a problem in establishing reproduction in mixed conifer habitats. In pine communities at lower elevations, however, soil moisture stress may be critical.

This study contributes to the understanding of forest vegetation in eastern Shasta County. It also helps to describe the transition between Sierra Nevada and Cascade vegetation types. Many species not specifically recorded in Shasta County in published floras were collected. Some collections represented minor range extensions.

Ecological connections between the westside and eastside pine communities are revealed in the Burney region. The separation between these types found along the Sierra Nevada may have been altered here by the development of the Pit River Canyon.

The vegetation drought index described in this study is only a preliminary effort. Plant indicators of moisture conditions should be evaluated in the context of nutrient, temperature, and other environmental gradients not yet available.[6]

Results suggest that this index may be of only limited help to a careful observer who is familiar

[6] Tentative species' drought values are available upon request to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701

with the area in question. His intuitive appraisal of plant indicators may give satisfactory results. But to an observer less experienced with local vegetation, the listing of obvious species and computing a VDI could be useful. The low number of species growing in some communities, particularly at higher elevations, does limit the application of this method. Fortunately, most of the "usable" indicator species can be found in most habitats even after drastic disturbance.

This study also supports previous observations that plant indicator studies must be relatively local. Some species which are associated with mesic habitats in the study area appear to be rather insensitive to moisture conditions 50 km. away in the Klamath Mountains.

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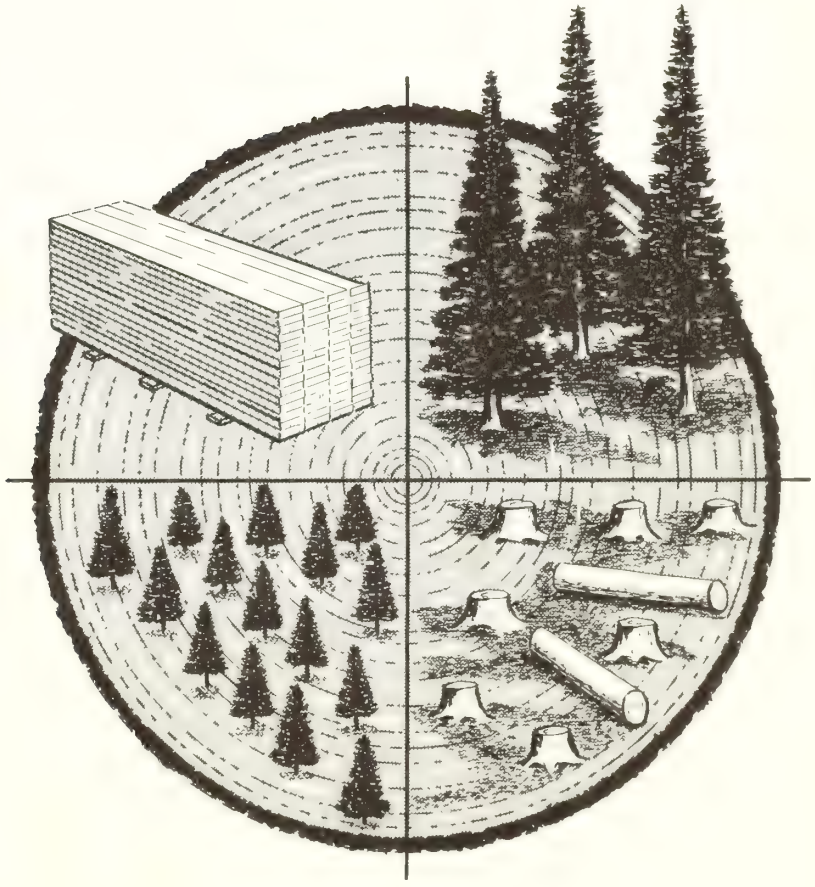
ECONOMICS OF REPLACING YOUNG-GROWTH PONDEROSA PINE STANDS

. . . a case study



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Economics of Replacing Young-Growth Ponderosa Pine Stands . . . a case study

DENNIS E. TEEGUARDEN

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Stands of young-growth ponderosa pine *(Pinus ponderosa)* grow on 1½ million acres of California's forest lands. How best to manage these stands is of concern to both public and private forest managers. Research aimed at developing the best silvicultural techniques is being done by both public and private agencies.

At the Pacific Southwest Station's Challenge Experimental Forest, Yuba County, California, researchers are studying methods of managing young-growth ponderosa pine stands at the lower elevations of the Sierra Nevada. Their work is directed at finding effective, low-cost techniques of regenerating pine and associated conifers after a harvest cut.

Many stands on the Experimental Forest are 80 to 90 years old. They are growing below the rate that yield studies suggest might be expected on comparable sites elsewhere. Their age, the large capital investment represented by growing-stock, and the presence of trash hardwoods that preempt growing space in some stands have raised questions about when the aging stands should be replaced with a new tree crop.

This paper reports a study of selected young-growth ponderosa pine stands on the Challenge Experimental Forest—how much they grow in value and when would be the best time to replace them. Specifically, the study sought an answer to the question: Is the best financial alternative to: (a) harvest the stands now, replacing them with new tree crops, or (b) hold the stands without thinning or pruning for harvest in the future? Because of the already advanced age of the stands, the alternative of holding them with a regime of thinning or pruning to increase earning rate on the growing-stock investment was not considered in this study. The method used in the study may prove useful in planning young-growth forest management. The specific technique of evaluating stand growth performance can be applied to many management situations and to any type of forest stand.

Challenge Experimental Forest

The Challenge Experimental Forest lies on the west side of the Sierra Nevada, about 38 miles east of Marysville, California, at elevations ranging from 2,500 to 3,600 feet. The terrain is generally gentle to moderately sloped. Soils are deep, well-drained, and of the Aiken series. The forest is primarily young-growth, with a few residual old-growth trees in some stands. About 55 percent of the forest's 3,520 acres are classified as pine type, 20 percent as pine-Douglas-fir, and 19 percent as pine-Douglas-fir-fir.[1] Black oak, tanoak, and Pacific madrone grow in varying degree throughout the Experimental Forest. Site index ranges from 100 to 170 feet.[2]

Cutting in the vicinity of the Experimental Forest first began about 1855, when the first sawmill was built. Old-growth stands were often clearcut to provide lumber for local gold mines and new settlements. Some areas were burned and subsequently invaded by brush. The Experimental Forest apparently developed by natural regeneration on such heavily cutover or burned areas. Remnants of old fence lines indicate portions of the Forest had been grazed or farmed and later abandoned.

Re-establishment of the Forest began in the 1870's. Apparently the ground was restocked naturally over a period of years in "waves" of regeneration that coincided with good seed crops and favorable soil moisture conditions. After the first "wave," others were less successful owing to the presence of established trees. Ages of 144 trees on three adjacent stands cut in 1963 ranged from 52 to 100 years; 63 percent, however, were in the 71–90 year age-class; they averaged 75 years. Owing to initial open condition of the forest, there is substantial hardwood stocking in many stands.

[1] Based on type classifications defined by Society of American Foresters. *Forest cover types of Western North America.* pp. 24–29. Washington, D.C., 1945.

[2] The index is in terms of the average total height of dominant ponderosa pine trees at a base age of 100 years measured at breast-height. Based on Arvanitis, L.G., *et al. Site index curves for even-aged young-growth ponderosa pine of the west-side Sierra Nevada.* Calif. Forestry and Forest Products 35, Univ. Calif. School of Forestry, Berkeley, Calif. 1964.

Economic Criteria for Replacement Decisions

The decision to replace a timber stand arises because assets in the form of growing-stock eventually are subject to diminishing productivity. For example, growing-stock of an even-aged forest increases over time as annual growth accumulates. Growth in a given time-period is the output which results from an investment of growing-stock and of land at the beginning of the period. This output is "stored" on the starting growing-stock and becomes part of it for the following growth period. Eventually, as the stand ages, growth diminishes relative to the input of growing stock. One element of urgency to replace the stand arises from the declining productivity of accumulated growing-stock. As the earning-rate on additional investment in growing-stock declines over time, the question arises as to when the stand should be replaced, or the rotation ended.

Typically, the forest manager has not one but many stands in different age-classes, on sites of varying productivity, and characterized by different degrees of stocking. His replacement problem is similar to that of an investor in corporate stocks or bonds who periodically examines his portfolio to determine which assets have prospective earning-rates below a minimum acceptable rate—possibly a rate which capital funds can earn in alternative investments. Similarly, the forest manager can review his portfolio of growing-stock assets to determine which trees or stands offer prospective earning-rates which have fallen to unacceptable levels. By replacing such assets, he improves productive efficiency of invested capital.

One approach to determining the best time to replace an aging stand stems from the view of forestry as a problem in capital management. The criterion for replacement is: harvest if the stand's prospective value growth-percent is less than the guiding minimum acceptable rate, or symbolically:

$$\text{Harvest if:} \quad \frac{dg}{G} < p \qquad (1)$$

in which: dg = prospective 1-year growth in value (dollars per acre)

G = present capital value of stand (dollars per acre)

$\frac{dg}{G}$ = prospective value growth-percent, or stand earning rate expressed as compound interest

p = alternative rate of return.

The value growth-percent (dg/G) measures how efficiently the stand accumulates capital values. It is obtained for a 1-year period by expressing stand value growth as a percent of the value of the stand. Closely related to value growth percent is the volume growth percent, which is a measure of how efficiently the stand accumulates board feet, cubic feet, or other physical units of product.

The alternative rate of return is the rate of interest that the timber owner expects for the use of his capital. It can be considered a *performance standard*. It is the highest interest rate that can be earned on funds removed from the stand and placed in another investment that is equivalent in risk. Or it can be the annual percentage at which an individual discounts future values in his decisions about current versus future consumption. In this study, an alternative rate of return of 4 percent is used as the standard for evaluating stands on the Experimental Forest.

The simple replacement decision model (Equation No. 1) implies that the only cost of delaying a timber harvest is the income foregone from alternative use of capital invested in growing-stock. But a decision to postpone harvest involves committing *two* resources to use by the stand for another period: (a) growing-stock capital; and (b) land or the site. And both land and growing-stock capital may earn income in alternative uses, including growing future crops of trees. This potential income from alternative land-uses is an implicit cost of postponing harvest which must be entered in the replacement model on the cost side. It then follows that *the optimum time to replace the stand is when its prospective value growth equals the alternative return on the invested capital in growing stock plus the annual rental value of the site.*[3] This criterion is expressed symbolically as:

$$\text{Harvest if:} \quad dg < Gp + a \qquad (2)$$

in which: Gp = stock-holding cost, expressed as interest charges on present growing-stock investment in dollars per acre

a = land-holding cost, expressed as the annual rental value of the site in dollars per acre.

The expanded replacement model says the following: compare the anticipated income from the

[3] For a more complete explanation of the model, see: Bentley, William R., and Teeguarden, Dennis E. *Financial maturity: a theoretical review*. Forest Sci. 11:76–87, 1965.

present stand to the anticipated income from alternative use of growing-stock capital and land; if the latter is greater, the stand should be replaced because net revenue can be increased by releasing capital and land for more profitable uses. For example, suppose the growing-stock capital for a given stand is valued at $1,000 at the beginning of a season's cutting period, and value-growth forecast for the next year is $60. Earning-rate on growing stock capital is $\frac{60}{1000}$, of 6 percent. If the alternative rate of return is 5 percent, and if rental value of the land is zero, the stand should be held, since income is greater under this plan ($60) than in the alternative investment ($1000 $\times$ .05 $=$ $50). Suppose, however, the annual rental value of the site is $15. Then cost of postponing harvest is $50 (implicit interest charges on growing-stock capital) plus $15, or $65, a sum greater than value growth of the present stand. Thus the stand should be scheduled for replacement.

Land-holding cost is determined by the owner's alternative opportunities for use of the land. If the "best" use of the land is for timber growing, land-holding cost is the annual equivalent of the net income earned from growing future crops of trees. In this paper, we show how estimates of site rent may be derived and present estimates for young-growth ponderosa pine under certain specific assumptions. On the other hand, if best use is some non-timber activity such as agriculture, the value of land for such use is entered in the decision equation. This change may imply ultimate shift of the land to non-timber uses. In this study, we assumed that land at the Experimental Forest will continue to be devoted to growing timber, and thus site rent is taken as the annual equivalent of net income from growing future tree crops.

This study explores the economics of replacing young-growth pine stands using the expanded replacement model. To answer the question "Should the stands be replaced, or should they be held for harvest at some future date?", the expected value growth of each stand under alternative future stumpage price levels is compared with the cost of delaying harvest, i.e., the sum of anticipated stock-holding and land-holding costs.

Growth Performance of Selected Stands

Five stands whose growth performance raises questions concerning their replacement are evaluated in this paper. The stands are similar to others on the forest *(table 1)*.

First, growth performance of each stand will be evaluated by comparing the anticipated earning-rate on growing stock capital with the alternative rate of return. An earning-rate on growing stock investment below 4 percent indicates the best plan is to replace the stand. But any higher rate would call for further analysis to consider land-holding cost.

In the study, we assumed that the decision to hold or replace is based on anticipated growth in capital values during the planning period 1963 to 1969. As background for the analysis, we studied actual stand growth performance for the period 1959–1963.

The Period 1959-1963

In 1959, inventories of the five stands ranged from 19,109 board feet per acre (Stand A) to 43,897 board feet per acre (Stand C) *(table 1)*. Capital values averaged $276 per acre and ranged from $174 to $419 per acre. Species composition of the stands was as follows:

	Stand				
	A	B	C	D	E
Species:	(percent of inventory)				
Ponderosa pine	84	71	70	72	80
Sugar pine	--	11	2	5	3
White fir	5	1	--	2	1
Douglas-fir	2	3	20	20	7
Incense-cedar	9	14	8	1	9
Totals:	100	100	100	100	100

Stand volume growth performance in the period 1959–1963 ranged from 629 to 953 board feet per acre per year *(table 1)*. Current research on young-growth ponderosa pine yields suggests that in stands 75 years old on site index 157, stocking averages 77,710 board feet per acre, annual growth over the life of the stand averages 1,036 feet per acre, and current 1-year growth is 630 board feet per acre.[4] Against this standard, current

[4] Provided by James L. Lindquist, School of Forestry and Conservation, University of California, Berkeley.

Table 1.--*Characteristics and volume growth performance of selected young-growth ponderosa pine stands, Challenge Experimental Forest, California, 1959 and 1963*[1]

Stand[2]	Area	Age[3]	Trees per acre		Average d.b.h.		Basal-area per acre 1959[4]	Total volume per acre		Average annual growth per acre	Volume growth percent[5]
			1959	1963	1959	1963		1959	1963		
	Acres	*Years*			*Inches*		*Sq. ft.*	*Bd. ft. Scribner*		*Bd. ft. Scribner*	
A (33B)	5.00	76	47	50	18.1	18.6	84	19,109	21,859	687	3.42
B (33A)	5.00	70	50	50	20.6	21.2	116	27,614	30,117	626	2.19
C (12)	2.64	70+	77	78	20.2	20.6	171	43,879	47,694	953	2.11
D (7)	3.00	70+	40	39	23.3	24.0	119	34,538	37,321	695	1.96
E (30A)	2.00	75	70	70	19.8	20.3	150	36,689	39,558	716	1.90

[1]Site index is 157 based on average height of dominant ponderosa pine trees at 100 years.

[2]Numbers in parentheses refer to compartment designation. Data for stands C and D are for permanent growth plots.

[3]Average age of trees 20 inches d.b.h. and larger at end of 1963.

[4]Trees 11 inches d.b.h. and over.

[5]Defined as the percentage rate, expressed as compound interest, at which beginning volume grows to equal ending volume.

Table 2.--*Value growth performance of selected young-growth ponderosa pine stands, Challenge Experimental Forest, California, 1959 to 1963*

Stand	Inventory value[1]		Volume growth	Value growth 1956 to 1963[2]
	1959	1963		
	—— *Dollars* ——		*Percent*	*Percent*
A	869	651	3.42	-6.9
B	1,196	889	2.19	-7.1
C	1,107	854	2.12	-6.3
D	1,018	777	1.96	-6.5
E	686	497	1.90	-7.7

[1]Calculated using stumpage price schedules A and B, Appendix A and inventory data in Table 7.

[2]Defined as the percentage rate, expressed in compound interest, at which beginning inventory value grows to equal ending inventory value.

Table 3.--*Inventory, by species, in selected young-growth ponderosa pine stands, Challenge Experimental Forest, California, 1959 and 1963*

Species	Stand									
	A		B		C		D		E	
	1959	1963	1959	1963	1959	1963	1959	1963	1959	1963
	Board feet Scribner									
Ponderosa pine	80,446	92,109	98,049	106,798	82,184	88,690	74,537	79,290	58,669	63,016
Sugar pine	--	--	15,791	17,334	1,643	1,845	4,709	5,374	1,987	2,140
Douglas-fir	1,836	2,343	3,567	3,897	23,137	25,734	20,875	23,367	5,547	6,149
White fir	4,820	5,089	1,313	1,553	175	209	2,319	2,689	375	416
Incense cedar	8,443	9,754	19,347	21,006	8,703	9,435	1,175	1,245	6,802	7,395
Totals	95,545	109,295	138,067	150,588	115,842	125,913	103,615	111,965	73,380	79,116

Table 4.--*Projected inventory in 1969, by species, selected young-growth ponderosa pine stands, Challenge Experimental Forest, California*

Stand	1969 Inventory				
	Ponderosa pine	Sugar pine	Douglas-fir	White fir	Incense-cedar
	Volume in board feet Scribner				
A	109,603	--	3,103	5,492	11,720
B	117,671	19,648	4,392	1,913	23,494
C	98,444	2,148	29,629	260	10,533
D	86,419	6,371	27,105	3,244	1,350
E	69,536	2,369	7,052	477	8,284

stands on the Experimental Forest are sub-stocked and have produced only 28 to 61 percent of the volume typically found on comparable sites. Although average annual growth per acre was still relatively high, volume growth relative to starting inventory investment during 1959–1963 ranged from 1.9 to 3.4 percent.

Growth in capital value.—If stumpage prices had remained stable, the rate of capital value-growth of the stands between 1959–1963 would be about the same as the volume growth percents shown in table 1. If we apply a 4 percent criterion, all five stands apparently had passed financial maturity by or before 1959. But if we apply a 3 percent rate, only stand A (with an earning rate of 3.3 percent) had not passed financial maturity.

In fact, the market situation deteriorated drastically during the period 1959–1963. At the Experimental Forest, prices received for young-growth pine stumpage averaged $3.88 per thousand board feet (MBF) less in 1963 than in 1959—a drop of 37 percent. During the same period, prices for old-growth ponderosa pine stumpage sold by the U.S. Forest Service in California declined an average of $4.80 per MBF, or by 23 percent.

Inventory values were drastically reduced by the decline in stumpage prices—more than enough to offset increases in physical inventory from stand growth *(table 2)*. In 1959, inventory values ranged from $686 (Stand E) to $1,196 (Stand B); in 1963, the range was $497 to $889. Reduction of capital values ranged from $43 per acre (Stand A) to $97 per acre (Stand C), and averaged $69 per acre for all stands. With the benefit of hind sight, it is clear all stands should have been replaced in 1959 if the planning period was 1959–1963.

The Period 1963-1969

In the future, stand volume growth-percent will decline because of further increases in growing stock and the likely reduction of growth. And unless the stand is pruned, prospects for significant improvement in quality are dim. Given this outlook in 1963, should the stands be replaced or held for future growth? Future stumpage prices obviously are a key factor that bears on the decision. If the prospects are for either constant or falling stumpage prices, all five stands should be replaced, for earning-rate on growing-stock investment in each case will be well below 4 percent. On the other hand, if prices are expected to rise, it may be advantageous to hold some or all stands in the light of anticipated growth in capital values. It is assumed that an increase in stumpage prices is more likely than constant or falling prices. Accordingly, interest centers on the relationship between stand earning-rates and possible increases in stumpage prices.

Lacking precise knowledge of future stumpage prices, analysis of the replace-or-hold decision might proceed in one of two ways. The first approach is to estimate the earning-rates from specific forecasts of future stumpage price levels. The replace-or-hold decision would then be made after comparing forecasted earning-rate with the alternative rate of return. The second approach is to find the level of stumpage prices necessary at some specific future date to make each stand's earning-rate equal the test criterion. Then the decision to hold or cut a stand could be based on the decision-maker's judgment as to future price levels.

Because the second approach is consistent with the decision criteria to be applied, and at the same time treats stumpage price as a variable, it is followed here.

Assumptions.—Earning-rate on initial capital value was computed for each stand for various price levels and for estimated volume growth rates. We assumed that:

1. The decision to replace or hold the stand is based on the prospective earning-rate on growing-stock capital during the planning period 1963–1969. A decision to hold could be revised at any time after 1963, of course, if anticipated conditions were to change. But a decision to cut, if carried out, is irrevocable.

2. The stands, and individual species components, grow in volume at the average annual rate experienced during the period 1959–1963 *(tables 3, 4)*.

3. Administrative, overhead, and property tax costs can be ignored because they are unaffected by the decision to cut or hold the stands.

4. Stumpage prices (a) remain constant at the 1963 level during the period; or (b) increase up to a maximum of 50 percent over their 1963 level, with the exception of white fir and cedar prices, which remain constant.

5. For a private owner, income from selling stumpage is subject to a 25 percent capital gains income tax. Selling costs are $0.50 MBF, and are deducted from gross stumpage value in calculating taxes. The depletion basis is assumed to be zero.

Stand earning-rate was estimated by obtaining

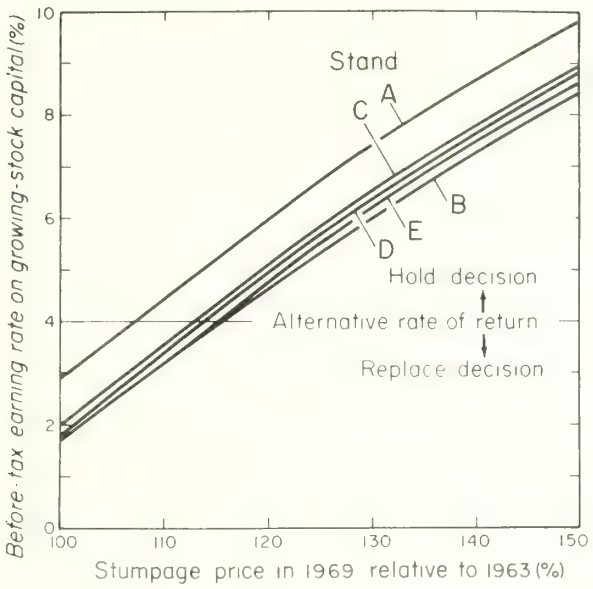

Figure 1.—*Earning-rate on growing-stock capital for the period 1963–1969.*

from a compound interest table the rate of interest corresponding to the value given by the following equation:

$$\sqrt[n]{V_n/V_o} - 1 \qquad (3)$$

in which: $n = 6$, number of years in the planning period
V_n = value of inventory in 1969, dollars per acre
V_o = value of inventory in 1963, dollars per acre

Compound interest rates corresponding to different values of n and V_n/V_o may be found in many publications.

Financial analysis.—Each stand's prospective growth performance under the foregoing assumptions was computed *(fig. 1; table 5)*. The following discussion considers the before-tax case, appropriate to a public owner.

If no change in stumpage prices is assumed, none of the stands have earning rates greater than 4 percent. Thus if the 4 percent return criterion is applied, the decision would be to replace all stands. If a 3 percent return is the standard, stand A might be held, but only if land-holding cost—potential net annual income from a future crop of trees—is zero.

If we assume prices will increase by 25 percent, growth in stand capital values range from 5.3 to 6.7 percent *(table 5)*. If the criterion of a 4 percent return is applied under this price outlook, then all stands should be held at least until 1969. Further analysis, however, is required to take account of land-holding cost.

If, as appears to be the case, stumpage prices will probably increase rather than remain constant, a critical factor is the minimum increase in stumpage prices required to justify holding the stands rather than replacing them. The critical price can be found by determining the relative price level in 1969 that is associated with a prospective stand earning-rate just equal to the alternative rate of return *(fig. 1)*. Consider stand C, in which a 13 percent price increase yields an earning-rate equal to 4 percent. Should the decision-maker anticipate that stumpage prices will rise this much, stand C would be held for cutting sometime after 1969. In contrast, stand A requires only a 7 percent price increase by 1969 to justify a holding decision. To justify holding all stands, a stumpage price increase of at least 15 percent must be anticipated by 1969.

The decision-maker may wish to plan his timber operations without regard to the influence of price changes on capital values. But if he does so, he is essentially acting as if prices will remain constant. And under this outlook all stands would be replaced. A possible upward drift in stumpage prices appears to be the only reason for delaying their replacement.

To sum up, an *increase* in stumpage prices (ponderosa pine, sugar pine, and Douglas-fir) of about 15 percent is necessary to justify delaying replacement of stands B, C, D, and E; stand A requires only a 7 percent increase. Prices probably will increase by these amounts and possibly more. Before a decision can be made, however, land-holding cost must also be considered. Accordingly, the next step is estimate this second type of holding cost.

Potential Net Income from Future Crops

The first step in analyzing timber replacement decisions is to estimate the value growth of the stand. Sometimes the decision to hold or cut a stand can be based solely on its prospective earning-rate, given the rate of return criterion. This decision may be made if the earning-rate on growing-stock investment is below the alternative rate of return, or if there is no land-holding cost arising

Table 5.--*Prospective growth in value, selected young-growth ponderosa pine stands, Challenge Experimental Forest, California 1963 and 1969*

CONSTANT STUMPAGE PRICES

Stand	Inventory value		Value growth		Earning-rate[4]	
	1963[1]	1969[2]	Before taxes	After taxes[3]	Before taxes	After taxes
	Dollars per acre				*Percent*	
A	130.46	155.60	25.14	17.30	2.9	3.0
B	177.93	197.22	19.29	14.22	1.7	1.7
C	323.75	363.59	39.84	27.74	2.0	1.9
D	259.35	289.30	29.95	20.83	1.8	1.8
E	248.65	275.88	27.23	18.82	1.7	1.7
STUMPAGE PRICES RISE 10 PERCENT OVER 1963 LEVEL BY 1969						
A	130.46	169.38	38.92	27.63	4.4	4.6
B	177.93	214.58	36.65	27.24	3.2	3.3
C	323.75	397.68	73.93	53.30	3.5	3.6
D	259.35	316.89	57.54	41.59	3.4	3.5
E	248.65	300.88	52.23	37.64	3.2	3.4
STUMPAGE PRICES RISE 25 PERCENT OVER 1963 LEVEL BY 1969						
A	130.46	192.29	61.83	44.81	6.7	7.0
B	177.93	243.05	65.12	48.60	5.3	5.6
C	323.75	453.66	129.91	95.28	5.8	6.0
D	259.35	362.06	102.71	75.47	5.7	6.0
E	248.65	342.46	93.81	68.74	5.5	5.8
STUMPAGE PRICES RISE 50 PERCENT OVER 1963 LEVEL BY 1969						
A	130.46	228.73	98.27	72.14	9.8	10.3
B	177.93	228.93	111.00	83.00	8.4	8.9
C	323.75	539.31	215.56	159.53	8.9	9.3
D	259.35	431.43	172.08	127.49	8.8	9.3
E	248.65	407.74	159.09	117.71	8.6	9.1

[1]Inventory values in Table 2 divided by stand area.

[2]Computed by applying stumpage prices schedules B, C, D, and E in Appendix to projected inventories in Table 4.

[3]Computed by subtracting selling costs of $0.50 per MBM and 25 percent capital gains tax from inventory values and subtracting 1963 after-tax inventory value from 1969 after-tax inventory value.

[4]Calculated by solving equation 3 (see text).

from continued use of the site. On the other hand, if future use of the site for other tree crops promises revenues greater than production costs, then the forgone net income should be considered in deciding to hold or to replace the present stand. This section attempts to obtain estimates of land-holding costs under specific assumptions regarding income-determining factors.

Method of Analysis

Given the management practiced, net income from future crops of ponderosa pine will depend on: (a) physical yields of saleable products, (b) prices, (c) initial costs of regeneration, (d) annual cash-flow [expressed as the difference between intermediate annual receipts and expenses for administration, protection, taxes, etc.], (e) interest rate, (f) income taxes [for the private owner], and (g) the rotation or replacement period.

In this study we assumed that future timber growing practices will be about what they have been in the recent past. Thus, we assume that stands will be regenerated within 1 or 2 years after final harvest; protected from fire, disease, and insects; and neither thinned nor pruned between regeneration and final harvest.

Management practices may be more intensive than this in the future. But, at present, thinning and pruning ponderosa pine stands are not widely practiced in California. More important, there is

not enough experience now as to the effects of these practices on yields or costs on which estimates of net income under more intensive management can be based. Presumably, thinning or pruning programs will be adopted if they can increase net income from managing ponderosa pine. Thus the estimates provided here should be viewed under the specific assumptions made. Furthermore, they should be considered an indication of minimum income levels which might be achieved under management policies similar to those in the past.

Net income from future crops of ponderosa pine was calculated by using a model in which the future rotation period is chosen to maximize the capitalized value of net incomes occurring every t years (t is a rotation period). This capitalized net income is also called *soil expectation value*. It may be converted to its annual cash-flow equivalent by multiplying it by the interest rate. In equation form:

$$SEV = \frac{NI_t}{(1+p)^t - 1} \qquad (4)$$

$$ACE = SEV\,(p) \qquad (5)$$

in which: SEV = soil expectation value (dollars per acres);
NI_t = periodic net income occurring every t years (dollars per acre);
t = rotation, or replacement period (in years since stand establishment);
ACE = annual cash-flow equivalent of the soil expectation value (dollars per acre per year).

This model allows for interest charges on timber investments and for the influence of postponing future crops on the optimal rotation period. It, in effect, defines the future optimum rotation in terms which are consistent with the replacement model given earlier.[5] It assumes that all future crops are identical as to yields, costs, values, and other income-determining factors. And it assumes that the owner can borrow or invest capital funds at the interest rate used in the model.

The soil expectation value represents the capitalized surplus of revenue over costs (including interest charges on investment). A positive value indicates the maximum price which could be paid for bare land and still cover all investment and other carrying charges plus earnings equivalent to the interest rate. A negative value indicates, for the assumptions made, that revenue is less than prospective production costs, i.e., the site is marginal for timber production.

The following model was used for computing periodic net income for alternative rotation periods:

$$NI_t = R_t - C_h - C_r\,(1+p)^t - C_a\frac{[(1+p)^t - 1]}{p} - T_x\left(R_t - C_h - C_r - \sum_{K=0}^{t} C_{ak}\right) \qquad (6)$$

in which: R_t = gross revenue from final harvest cut in year t, in dollars per acre. Computed by multiplying yields by unit price;
C_r = initial regeneration costs, dollars per acre;
C_a = annual fixed cash costs for administration, protection; and ad valoreum taxes;
T_x = capital gains or income tax rate, whichever is lower, expressed as a decimal;
C_h = harvesting costs, including marketing, selling, and supervision costs, dollars per acre. Computed by applying harvesting costs per thousand board feet to physical yield schedule;
and in which NI_t, t, and p are defined as above.

This model reflects the assumption of no thinning or pruning. Thus the only intermediate expenditures are the fixed annual costs for administration, protection, taxes, and other chargeable items.

The model includes explicit allowance for the capital gains or income tax. To compute the tax the appropriate tax rate is applied to the difference between gross stumpage receipts and harvesting costs plus depletion allowance. The depletion allowance is assumed to consist of initial regeneration costs (C_r) and accumulated annual expenses $\left(\sum_{K=0}^{t} C_{ak}\right)$. If these annual expenses are "charged off" against other current income in years when they occur, then they can be omitted from the tax calculation. Under Federal tax law, regeneration expenses must be carried in the depletion basis and recovered as a depletion allowance at final harvest.

For an owner subject to 50 percent income tax, cost items charged off against current income are equivalent to a real cost of $0.50 on the dollar because $1.00 so charged off reduces current income taxes by that amount. To take this figure into account in the model, the analyst may enter annual charged-off costs at one-half their actual sum.

[5] Bentley and Teeguarden, *op. cit.*

Table 6.--*Physical and value production schedules for young-growth ponderosa pine (site index 157)*

Age of stand	Average d.b.h.[1]	Yields per acre[2]	Stumpage price, schedule			Value production, schedule		
			1	2	3	1	2	3
		Bd. ft. Int.1/4	*Dollars per MBF*			*Dollars per acre*		
30	12.7	34,310	13.00	9.75	6.50	445.97	334.48	222.98
31	--	35,860	13.20	9.90	6.60	473.33	355.00	236.67
32	--	37,360	13.40	10.05	6.70	500.66	375.49	250.33
33	--	38,820	13.60	10.20	6.80	527.96	395.97	263.98
34	--	40,230	13.80	10.35	6.90	555.24	416.43	277.62
35	13.6	41,610	14.00	10.50	7.00	582.51	436.88	291.25
36	--	42,940	14.20	10.65	7.10	609.78	457.33	304.89
37	--	44,240	14.40	10.80	7.20	637.06	477.79	318.53
38	--	45,500	14.60	10.95	7.30	664.35	498.26	332.18
39	--	46,730	14.80	11.10	7.40	691.66	518.75	345.83
40	14.5	47,930	15.00	11.25	7.50	719.00	539.25	359.50
41	--	49,100	15.15	11.37	7.58	743.91	558.11	372.01
42	--	50,240	15.30	11.48	7.65	768.74	576.91	384.47
43	--	51,360	15.45	11.60	7.73	793.50	595.67	396.90
44	--	52,450	15.60	11.71	7.80	818.19	614.38	409.31
45	15.2	53,510	15.75	11.83	7.88	842.83	633.06	421.68
46	--	54,550	15.90	11.94	7.95	867.41	651.38	433.92
47	--	55,570	16.05	12.05	8.03	891.95	669.65	446.14
48	--	56,570	16.20	12.16	8.10	916.44	687.89	458.33
49	--	57,550	16.35	12.27	8.18	940.89	706.10	470.50
50	15.9	58,500	16.50	12.38	8.25	965.32	724.28	482.66
51	--	59,440	16.60	12.45	8.30	986.74	740.29	493.37
52	--	60,360	16.70	12.53	8.35	1,008.05	756.22	504.02
53	--	61,260	16.80	12.60	8.40	1,029.24	772.05	514.62
54	--	62,150	16.90	12.68	8.45	1,050.33	787.81	525.17
55	16.2	63,020	17.00	12.75	8.50	1,071.33	803.49	535.66

[1]Trees 4.5 inches d.b.h. and larger. Calculated with equation:

$$-69.59157 - 13.54381 \log_{10} (\text{age}) + 27.84599 \log_{10} (\text{age X site index}) \quad (R^2 = .68).$$

[2]Calculated using the following empirical yield equation:

$$Y = -546173.69 + 109078.0 \log_{10} (\text{age}) + 190973.0 \log_{10} (\text{site index})$$

where:

Y = yields in board feet (International 1/4-inch log scale), trees 10 inches d.b.h. and larger, to 6-inch top.

To solve the soil expectation equation, an iterative procedure was followed. For each set of income-determining factors, the soil expectation value was obtained for alternative rotations ranging from 30 to 55 years. The procedure permitted selection of the rotation yielding the maximum capitalized value of periodic net incomes.

Assumptions

Physical Yields

Yields of sawtimber for site index 157 are the best available estimates *(table 6)*. They were computed with the following preliminary empirical yield equation for young-growth ponderosa pine:[6]

$$Y = -546173.69 + 109078.0 \log_{10}(\text{age}) + 190973.0 \log_{10}(\text{site index})$$

in which: Y = yields in board feet, international ¼ inch log scale, for trees 10 inches d.b.h. and larger to 6 inch minimum top diameter.

The equation is for stands with a basal area composition that averages about 85 percent ponderosa pine. It is based on data from 204 sample plots located in the Sierra Nevada.

Site index is estimated to be 157, the average index computed from a sample of 27 trees taken in four stands on Challenge Experimental Forest. It is based on average total height of dominant ponderosa pine at 100 years, with age measured at d.b.h.

[6] Provided by James L. Lindquist, School of Forestry and Conservation, University of California, Berkeley.

Average stand d.b.h. of trees 4.5 inches and larger was computed with the following equation which is based on data from the same 204 plots used to develop the yield equation:

$$\text{d.b.h.} = -69.59157 - 13.54381 \log_{10}(\text{age}) + 27.84599 \log_{10}(\text{age} \times \text{site index}).$$

Stand Composition

Ponderosa and sugar pine were assumed to constitute 85 to 90 percent of stand volume indicated by yield equation, and Douglas-fir the balance.

Prices

Three stumpage price schedules *(table 6)* were examined. Schedule 3 assumes that prices of ponderosa pine stumpage (in 1963 dollars) for stands averaging 18–21 inches d.b.h. will increase to about their 1959 level—$10 per MBF—in the next 30 years and then remain constant. This assumption may be somewhat conservative. Schedule 2 assumes that stumpage prices will increase to a level of $15 per MBF (50 percent greater than in 1959) in 30 years and then remain constant. Schedule 1 assumes stumpage prices will increase to $20 per MBF in 30 years and then remain constant. Prices are net of selling costs.

None of these stumpage prices actually appears in *table 6* because they are for the 80-year-old stand anticipated to average 19 inches d.b.h. The basic prices were adjusted to reflect higher conversion costs in younger, smaller-diameter stands. Adjusted prices are shown only for ages up to 55 years. From a study by Baker,[7] we calculated stumpage prices for stands averaging 10 inches d.b.h. at one-half the assumed price for a 19-inch d.b.h. And we assumed that prices for intermediate diameters would increase linearly to the price levels of $10, $15, and $20 per MBF established for a stand averaging 19 inches d.b.h. Pine prices were also applied to Douglas-fir.

Interest Rate

The basic interest rate is the 4 percent alternative rate of return adopted previously. But net incomes were also computed for rates of 3.5, 4.5, 5.0, and 5.5 percent.

Costs

Five levels of regeneration cost were examined: $30, $60, $70, $90, and $120 per acre. This range corresponds to actual costs of seeding and planting new tree crops in California, where seeding generally ranges from about $30 to $60 per acre, and planting from $60 to $120, depending on amount of site preparation and other factors. In spite of cost differences, planting is now the preferred regeneration technique. It is estimated that slash disposal and planting under conditions at the Experimental Forest would now cost about $90 per acre. This figure is close to the lowest cost of slash disposal and planting 436 trees per acre in group selection cuttings in 1963 in the adjacent La Porte Ranger District, Plumas National Forest. Cost of direct seeding with prior slash disposal on the Challenge Experimental Forest ranges from $30 to $70 per acre.

Annual carrying costs for protection, administration, ad valorem taxes, and road maintenance are calculated at two levels: $0.50 and $1.00 per acre per year. For a private owner in the 50 percent income tax bracket, who charges off such costs against current income, equivalent *actual* annual costs are one-half the levels used in the analysis.

Income Taxes

Net income estimates were made under the assumption of no income tax and of a 25 percent capital gain income tax. In the latter case, it was further assumed that annual fixed costs are charged off rather than being added to the depletion basis. It should be emphasized that the optimal rotation periods are not indications of the rotations which should or may in fact be practiced 30 or more years from now. Their chief importance here is the basis they provide for estimating soil expectation values.

Results

For a range of assumptions regarding stumpage prices, regeneration costs, and annual carrying costs, we estimated the annual cash-flow equivalent (ACE) of soil expectation values *(figs. 2, 3)*. The estimates assume a 4 percent alternative rate of return. For brevity, ACE estimates for other interest rates are omitted from this publication.[8] The following summarizes results.

For a 4 percent rate of return and no capital gains income tax, ACE ranges from $5.82 to —$3.28 per acre depending on the other determinants of net revenue *(fig.2)*. With taxes deducted,

[7] Baker, Vernon W. *Economic guides to young-growth ponderosa pine management*. U.S. Dep. Agr. Soil Conservation Serv. SCE-TR-133, 1958. (Unpublished.)

[8] Tables giving estimates of annual net cash-flow equivalent (ACE) and optimal rotations may be obtained by writing to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

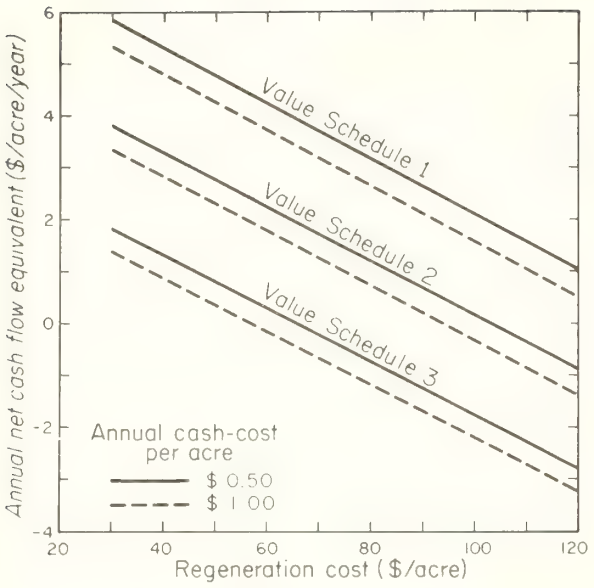

Figure 2.—*Relationship between annual net cash-flow equivalent, regeneration cost, value schedule, and annual cash-cost under assumption of 4 per cent and no income tax.*

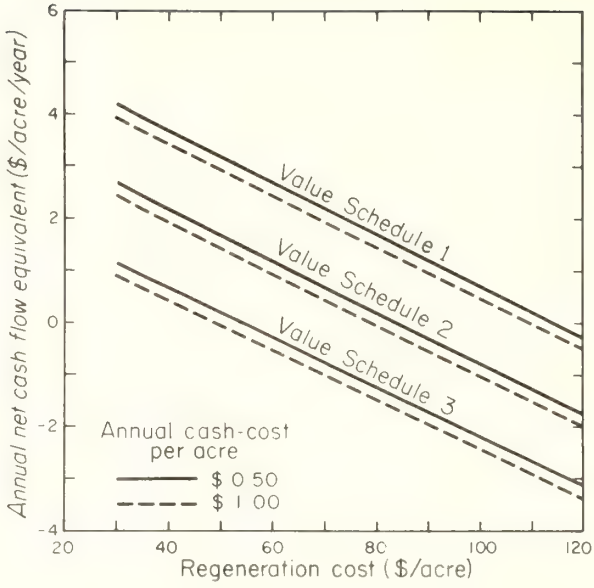

Figure 3.—*Relationship between annual net cash-flow equivalent, regeneration cost, value schedule, and annual carrying cost under assumption of 4 per-cent return and 25 per cent income tax.*

ACE ranges from $4.19 to —$3.41 per acre *(fig. 3)*. We found that ACE is especially sensitive to initial regeneration cost and to the stumpage price level.

Optimal rotation periods will be of interest to many forest managers who are responsible for planning young growth timber production. Under the assumptions noted previously, optimal rotations ranged from 30 to 40 years. In general, rotations increase as regeneration cost increases, as interest rate decreases, and as stumpage prices decrease.

Optimal rotation periods under a 4 percent rate of return ranged from 33 to 38 years. These rotation lengths imply growing future ponderosa pine stands on site index 157 to an average diameter of about 13.5 inches d.b.h. (stems 4.5 inches and larger), which is below current merchantability standards. For trees 11 inches and larger, however, average diameter will probably be closer to 16 inches d.b.h. The trend is toward using smaller diameter material, so these future tree sizes perhaps are not unrealistic. In any case, even after allowing for higher unit value as stand diameter increases, rotation periods of 33 to 38 years maximize ACE. To assume stands should be grown to older ages and larger diameters would imply less efficient use of capital in growing stock and land.

The Replacement Decision

To illustrate how the replace-or-hold decision was evaluated in view of both stock-holding and land-holding costs, we will use an example. In *table 7*, column 2 shows each stand's prospective capital-value growth during the planning period. This growth is the result of volume growth and increases in stumpage prices. Because the Experimental Forest is publicly owned, we assumed that there is no capital gains income tax. Stock-holding cost, (column 3) is the income that could be earned if the growing stock capital in 1963 were invested in some other investment that yields a 4 percent return. This cost, accumulated for 6 years, was computed as follows:

$$G_0 (1 + p)^n - G_0 \qquad (7)$$

G_0 is beginning inventory value in 1963 (from table 5), p is the alternative rate of return expressed as a decimal (0.04), and n is the planning period (n=6). The term $G_0(1+p)^n$ determines the

value of the beginning inventory, G_0, at the end of n years if it were invested at p interest. G_0 subtracted from this value gives income from the alternative investment.

Land-holding cost (column 4) is an estimate of net value which could be produced if the site were released for use by new regeneration. The decision to hold the present stand until at least 1969 requires that its value growth be at least equal to stock-holding cost *plus* land-holding cost.

Land-holding cost for the planning period was computed as follows:

$$\frac{a\,(1 + p)^n - 1}{p} \qquad (8)$$

in which a is the annual cash-flow equivalent (ACE) of soil expectation value, as estimated in figure 2 under various assumptions, plus annual fixed cash costs, C_a. Annual fixed cash-costs must be incurred regardless of whether the current stand is replaced or held, and therefore must be added to ACE to estimate annual land-holding cost. Assuming value schedule 1, $60 regeneration cost, annual carrying costs of $0.50 per acre, and no tax on income, ACE is $4.19 *(fig. 3)*. Adding $0.50 yields an annual land-holding cost of $4.69 per acre. Equation (8) accumulates annual land-holding cost for n years to determine total land-holding cost for the planning period. Substituting $4.69 for a, land-holding cost for the 6-year period under a 4 percent return is $31.05.

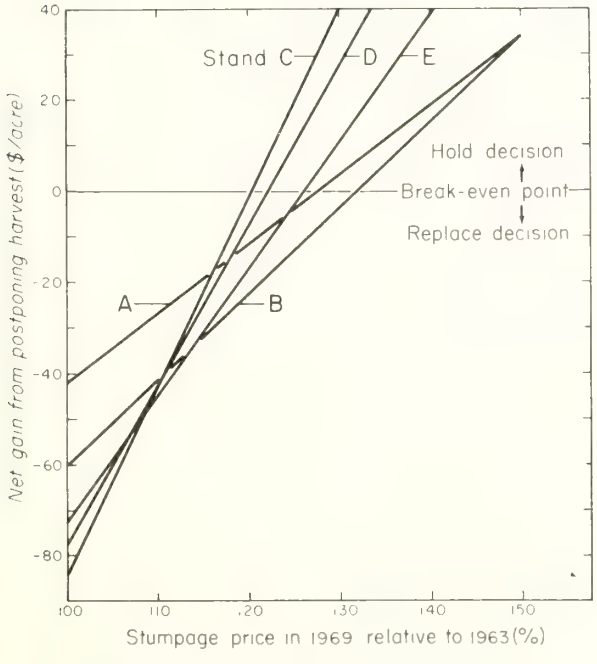

Figure 4.—*Relationship between net gain from postponing harvest and prospective change in stumpage prices.*

To determine the net gain from holding a stand until 1969, the sum of stock-holding and land-holding costs is subtracted from expected value growth (column 2 less column 5). A positive figure (column 6) indicates that the most profitable plan is to hold the stand until at least 1969.

The analysis suggests that all five stands should be replaced if stumpage prices are expected to rise by only 10 percent or less. But if prices are expected to rise by 25 percent over their 1963 level, the decision is to hold stands C and D.

The relationship between net gain from holding each stand and stumpage prices ranging from an index of 100 (constant prices) to 150 percent (1969 prices 50 percent higher than in 1963) is shown in *figure 4*. By reading-off along the break-even line the price index which produces a net gain from holding just equal to zero, the minimum price increase required for a holding decision can be determined. Take stand A as an example. Unless prices rise by at least 28 percent above their 1963 level, the costs of holding stand A will exceed value growth by an amount that depends on the actual price level in 1969. But if prices remain constant, holding cost will exceed anticipated value growth by about $42 per acre. Price increases which lead to a holding decision are:

Stand:	Minimum price increase to justify holding (percent)
A	28
B	32
C	20
D	22
E	26

Recommended Management Plan

The recommended management plan is to schedule stands A, B, and E for replacement and to hold stands C and D for harvest sometime after 1969. This plan assumes application of a criterion of 4 percent return. And it further assumes that a $60 per acre regeneration cost is a reasonable outlook considering recent experience with direct seeding, that stumpage prices for future tree crops will in 30 years reach the $20 level, and that prices during 1963–1969 will increase by 25 percent. Any indication that prices may not attain expected

levels is enough reason to reconsider the plan to hold stands C and D.

If stands A, B, and E cannot all be harvested in the first year of the planning period, cutting priorities should be established so that stands with the largest *negative* net gain from holding are replaced first. In this way the cost of postponing their harvest is minimized. Thus *figure 4* indicates stand B should be replaced first, followed by A and then E. However, if the prospective stumpage price increase is less than 25 percent replacement priority changes.

To explore the sensitivity of the replace-or-hold decision to determinants of land-holding cost analyses similar to *figure 4* were made under alternative assumptions regarding regeneration cost and prices for future tree crops.[9] Other factors were held fixed at the levels assumed in the recommended plan. The results indicate the best plan is sensitive to prospective outlays to establish regeneration and to future prices:

If regeneration cost is	*Replace stands*
$90	B
60	A, B, E
30	A, B, E, D

Under value schedule	*Replace stands*
1	A, B, E
2	B
3	(hold all stands)

Low regeneration costs favor a replacement decision because land-holding cost—the cost of delaying the start of a new tree crop—is correspondingly higher. Unless the prospective value growth of the current stand is great enough, a decrease in regeneration cost may shift a stand from a holding to a replace decision, as in the case of stand D when assumed regeneration cost is $30 per acre rather than $60. Conversely, a holding decision is favored by the prospect of low prices for future tree crops because land-holding cost is correspondingly lower. This is why all stands shift to a holding decision if value schedule 3 is in prospect.

A private timber owner may wish to know how a 25 percent capital gains tax on net revenue would affect the replace-or-hold decision. Using

[9] These analyses used data from *table 5* and *figure 3*. The analysis may be replicated by following procedures described in the section on *The Replacement Decision*.

Table 7.--*Analysis of the replacement decision*

Stand	Capital value growth 1963 to 1969	Opportunity costs at 4 percent interest			Net gain from holding	Decision
		Stock-holding cost	Land-holding cost[1]	Total cost		
	Dollars per acre					
STUMPAGE PRICES INCREASE 10 PERCENT OVER 1963 LEVEL BY 1969						
A	38.92	34.84	31.05	65.89	-26.97	Replace
B	36.65	47.15	31.05	78.20	-41.55	Replace
C	73.93	85.79	31.05	116.84	-42.99	Replace
D	57.54	68.73	31.05	99.78	-42.24	Replace
E	52.23	65.89	31.05	96.94	-44.71	Replace
STUMPAGE PRICES INCREASE 25 PERCENT OVER 1963 LEVEL BY 1969						
A	61.83	34.84	31.05	65.89	- 4.06	Replace
B	65.12	47.15	31.05	78.20	-13.08	Replace
C	129.91	85.79	31.05	116.84	19.67	Hold
D	102.71	68.73	31.05	99.78	9.53	Hold
E	93.81	65.89	31.05	96.94	- 3.13	Replace

[1] Computed at $4.69/acre per year accumulated with interest for period 1963 to 1969. Based on stumpage value schedule 1; $60 regeneration cost; annual cash-cost of $0.50 per acre; and no tax on income. Fixed annual cash cost is added back into ACE since it is common to present and future stands and thus need not be taken into account.

data from *table 5* and *figure 3* as the basis for decision, if a tax must be paid on present and future harvests the recommended plan is to schedule stands A and B for replacement and to hold stands C, D, and E.[10] Thus the effect of considering the income tax is to shift stand E from a replace to a holding decision.

On the Experimental Forest land-holding cost is a significant element in the economics of replacing pine stands. For example, if only stock-holding cost is considered, stand B requires a 15 percent price increase to raise the net gain from holding above the break-even line *(fig. 1)*. But if land-holding cost is also considered, stand B requires a 30 percent increase in price to justify delaying its replacement.[11] Total cost of holding stand B is $78.20 per acre, $31.05 of which is land-holding cost *(table 6)*. For all stands examined land-holding cost ranges from 26 to 47 percent of total holding cost *(table 7)*.

Land-holding costs were estimated under the assumption of a management policy involving neither thinning nor pruning. Such practices would be adopted if they increase soil expectation value, i.e., if they add more to prospective revenues than to costs. Thus expected increases in future net income arising from thinning and pruning programs in effect raise the cost of delaying replacement of current stands. Given such an outlook, the decision to hold the stand may have to be reconsidered, particularly in instances where the net gain from holding appears relatively small.

[10] Assumes $60 regeneration cost, value schedule 1, and $0.50 per acre per year carrying cost.

[11] This figure assumes $60 per acre regeneration cost, value schedule 1, no tax, and annual carrying charges of $0.50 per acre per year.

Summary

To sum up, all five stands should be scheduled for replacement unless stumpage prices are anticipated to increase during the planning period 1963–1969. Under a constant-price outlook, earning-rates on growing-stock capital and land values are well below the 4 percent alternative rate of return. It appears likely, however, that prices may increase 25 percent or possibly more. Thus the recommended plan is to replace stands A, B, and E and to hold stands C and D. This plan is based on specific assumptions regarding factors which influence the replace-or-hold decision. Should the outlook be different than the assumptions which have been made, the recommended replacement schedule should be reconsidered.

Appendix

Stumpage Price Schedules Used in Computing Current Stand Values

To estimate stand capital values in 1959 and 1963, prices paid for stumpage sold on the Challenge Experimental Forest in these years were applied to stand inventories shown in *table 3*. Stumpage price schedules used (schedules A and B) are as follows:

	1958	1963	1969		
	A	B	C	D	E
Species:	(dollars)				
Ponderosa pine	10.27	6.39	7.00	8.00	9.60
Sugar pine	7.30	6.20	6.80	7.70	9.30
Douglas-fir	10.15	9.69	10.70	12.30	14.50
White fir	1.79	2.71	2.71	2.71	2.71
Cedar	1.79	2.71	2.71	2.71	2.71

Prices are gross prices, rather than net of road building, slash disposal, or erosion control costs paid to the buyer. Schedules C, D, and E were computed assuming 10, 25, and 50 percent stumpage price increases from the 1963 base year. These schedules were applied to inventory data in *table 4* to obtain stand values in 1969 *(table 5)*.

GPO 976-117

Rainfall Interception by Annual Grass and Chaparral . . . *losses compared*

Edward S. Corbett and Robert P. Crouse

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The Authors

were formerly on the staff of the Station's San Dimas Experimental Forest, near Glendora, Calif., where they studied problems in flood and sediment reduction in brushlands. **EDWARD S. CORBETT,** a hydrologist, is now responsible for research on municipal watershed management at the Northeastern Forest Experiment Station, Upper Darby, Pa. He earned a B.S. degree (1958) in forestry at the University of Connecticut, and an M.S. degree (1960) in watershed management at the New York State University College of Forestry. **ROBERT P. CROUSE** is now principal resource analyst with the Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo., and stationed at Tucson, Ariz. A 1950 graduate of Amherst College, he holds an M.F. degree in forest management from Yale University (1958).

Interception is the first hydrologic process that redistributes precipitation near the ground. Hamilton and Rowe (1949) defined it as the portion of precipitation that is returned to the atmosphere through evaporation from plant surfaces or that is absorbed by the plant. Interception then, is the difference between the precipitation falling over an area and the part that reaches the soil.

Information on rainfall interception by several brush types of central and southern California is available from earlier studies (Rowe 1948; Hamilton and Rowe 1949). But little information is available on interception loss from native or seeded grass covers and from grass litter (*fig. 1*).

Much of the foothill and mountain brushlands of southern California serve primarily as watersheds. Chaparral vegetation covers some 8.5 million acres of the watersheds in the State (Wieslander and Gleason 1954). Chaparral uses large quantities of water, is a great fire hazard, and provides little forage for livestock. Through the years proposals have been made that these brushlands be converted to grass. According to such proposals, grass would be less hazardous than brush, and is a more useful vegetative cover.

Before any large-scale conversion can be undertaken, it is necessary to know the probable effects of any vegetative changes on water yield and on soil erosion. Several studies on the effects of brush conversion on soil moisture and streamflow have been made recently. Rowe and Reimann (1961) reported the relative use of soil moisture by brush, grass, and grass-forb vegetation. The way vegetative changes on chaparral-covered watersheds affect surface runoff, streamflow, and erosion has been described by Rowe (1948, 1963), Rowe and Colman (1951), Pillsbury *et al.* (1962), and Corbett and Rice (1966).

Figure 1.—*Annual grass, as it reaches full development in spring, can hold a large amount of rain in storage.*

This paper reports a study of rainfall interception loss from annual grass and grass litter (*Bromus mollis*) under natural conditions on the San Dimas Experimental Forest, in southern California. It describes relationships among growth stage of grass, storm size, and interception loss during three rainy seasons. The study was supported in part by the California Division of Forestry.

Interception Loss Defined

Some investigators believe that interception loss, as defined by Hamilton and Rowe (1949), is not a real loss to the plant-soil-water system. Instead, they propose two terms: *"gross interception loss"* to represent interception loss in that definition; and *"net interception loss"* to represent the part of the precipitation retained on vegetative surfaces and evaporated that does not affect a plant's water use. Studies by Burgy and Pomeroy (1958), Rakhmanov (1958), and McMillan and Burgy (1960) suggested that intercepted water causes a compensating reduction in transpiration. Burgy and Pomeroy

(1958) and McMillan and Burgy (1960) applied artificial rainfall to the foliage of grasses under laboratory and field conditions. They found little or no net loss of water from the entire plant-soil-water system.

Goodell (1963) has questioned how large the net interception loss might be, considering these factors: (a) Transpiratory regulation by plants under the stress of limited water availability; (b) probability that the energy available for evapotranspiration from wet leaves is greater than that from dry leaves, and (c) the possibility that under winter conditions in cold climates, transpiration is limited more by the availability of water than of energy, and that interception increases the quantity of water favorably exposed to the energy supply. Furthermore, Rutter (1959, 1964, 1967) has shown that the rate of evaporation of water intercepted by foliage of Scotch pine (*Pinus sylvestris*) is many times greater than the rate of transpiration—indicating a differential net loss. A similar conclusion for other species is alluded to by Patric (1966), Helvey (1967), and Leyton *et al.* (1967). And Thorud (1967) found that 91 percent of water artificially applied to the foliage of potted 6- to 7-year-old ponderosa pine (*Pinus ponderosa* Laws.) was a net loss to soil moisture supplies. The reduction in transpiration as a percent of applied water varied from 4 to 14 and appeared to be related to weather conditions. This finding indicates that to obtain *realistic* measurements of net interception losses, experiments should be conducted under actual storm conditions.

Interception loss on dead (non-transpiring) grass stubble and grass litter would be a net loss (Burgy and Pomeroy 1958; McMillan and Burgy 1960). But there may be a substantial reduction in soil evaporation owing to the insulation of a continuous litter layer (Blow 1955; Rowe 1955). On California's foothill ranges, Bentley and Talbot (1951) found that seeds of annual plants start to germinate after the first rains of ½ to 1 inch, which usually occur in October or November. Ordinarily most of the plants mature and dry in May. Thus annual grass vegetation is transpiring from late fall until early spring. During the rest of the year the foliage is dead.

The problem of assessing the magnitude of net interception loss is complicated by several factors. These factors include (a) the amount of living and dead plant surfaces; and (b) periods of minimum and maximum transpirational use as affected by season of year, time of day, climatic conditions, and soil moisture conditions. An assessment of the problem is beyond the scope of this paper. But Kohler (1958) points out that water intercepted by the vegetative cover is a net loss to surface precipitation and accordingly, can affect the surface runoff, soil moisture, and ground water phases of the hydrologic-cycle.

Magnitude of Grass Interception Loss

Early investigators of rainfall interception by grass include Musgrave (1938), who found that blue grass (*Poa spp.*) intercepted 17 percent of the rainfall during the month before harvest. But he did not account for stemflow (rainfall that reaches the ground by running down the plant stems) from the plants.

Clark (1940) placed narrow rectangular catch pans on the ground beneath a grass-forb cover in Nebraska. Where necessary he cut the plants and supported them in the pans by wires. Thus he recorded stemflow as part of throughfall (rainfall which reaches the ground through interplant spaces and as drip from leaves and stems) for some plants but not for others. Clark believed stemflow to be a minor factor in the redistribution of rainfall. The percent of interception loss varied with the amount of rainfall, density of foliage, and weather conditions. Interception percentages were generally quite high, but the amount of rainfall, artificial and natural, was usually low. For big bluestem (*Andropogon furcatus*) 22 to 36 inches in height; interception loss ranged from 84 percent to 47 percent as amount of applied water spray varied from ⅛ inch to 1 inch. Under conditions of natural rainfall, a stand of fully developed big bluestem had interception losses ranging from 97 percent from a light shower of 0.06 inch to 63 percent for a heavy rain and subsequent showers totaling 1.20 inches. Interception losses for shorter growing grasses were less. When 1 inch of rainfall was applied in 1 hour the interception value of stink grass (*Eragrostis cilianensis*) was 18 percent and that of buffalo grass (*Buchloe dactyloides*) was 26 percent.

In measuring stemflow separately for several field crops Haynes (1940) used catch pans similar

to those in the Clark study. He had difficulty in getting an accurate measure of stemflow under grass crops however, and did not report its value. Over two growing seasons, he found that interception (excluding stemflow) in a stand of bluegrass, including the previous year's accumulation of litter, was 56 percent of the 41.64 inches total rainfall. Both Clark (1940) and Haynes (1940) cited the problems caused by growth changes in the vegetative cover and the effects on interception, but did not quantitatively evaluate these changes.

Kittredge (1948) found that grass species of *Avena, Stipa, Lolium,* and *Bromus,* allowed to grow up over a trough gage 10 feet long and 4 inches wide, intercepted 25.9 percent of the 32.52 inches of seasonal rainfall. This value was not corrected for stemflow.

In contrast to Clark, Beard (1962), found that stemflow from grass made up a considerable portion of the rainfall reaching the soil. It ranged from 35 to 45 percent of the total rainfall during the sampling period. Interception loss from the grass (primarily *Themeda* and *Cymbopogon*) was about 13 percent of the total rainfall.

Study Methods

The San Dimas Experimental Forest, near Glendora, Calif., has a Mediterranean climate—hot, dry summers and mild rainy winters. Nearly all of the annual precipitation falls from November through April. Annual precipitation has ranged from 10 to 48 inches, and averages about 26 inches. About half the annual precipitation falls in storms 3 inches and larger. Records for 32 years show that mean monthly temperatures ranged between 47.3°F. in January and 72.6°F. in July and August. The average annual evaporation (U.S. Weather Bureau pan) was 63.1 inches over a 30-year period.

Measuring Interception Loss

A ½-acre study area was established on a 35-percent slope that had previously been converted from brush to grass. Hamilton and Rowe (1949) had used this same area to carry out their test on rainfall interception by chaparral. Sample sites on a 1/20-acre plot were burned to remove the old grass cover, litter, and undesirable seed. The sites were then seeded to Blando brome (*Bromus mollis*), a species commonly used in range and watershed conversion work and in reseeding brush burns. To hasten the establishment of a grass stand suitable for interception measurements, the sites were irrigated in fall after sowing.

After the grass cover became established, we drove 10-inch diameter metal collars into the soil so that about 1 inch of the collar remained above the soil surface. When the grass height reached 2 inches we sealed the soil surface within the collar. First, we sifted a layer of fine sand onto the soil to provide a uniform, sloping surface for drainage. Then we moistened the sand with water and applied two coatings of a neoprene latex emulsion (*fig. 2*). The tight, smooth, and durable seal obtained was non-toxic and did not affect the normal growth of the grass.

A drain in the side of each collar carried combined throughfall and stemflow to a collection can. Tipping bucket mechanisms were connected to five of the sites to measure the rate of combined

Figure 2.—*Demonstration of technique used to apply neoprene sealer to soil surface inside metal collar.*

Figure 3.—*Instrumentation used in the study shown by cutting away the grass at the end of a field season. A drain tube carried combined throughfall and stemflow to the collector. A tipping bucket mechanism was used to measure rate of flow.*

throughfall and stemflow (*fig. 3*). Twenty collars were installed the first year of the study and 40 the second and third field seasons.

Gross precipitation was determined from four rain gages placed in the corners of the study area and from two ground level gages near the center of the area. Three of the corner gages were 8-inch standard gages. The fourth was a tipping bucket intensity gage. During a portion of the study a weighing recording gage was also used.

Grass interception loss was calculated as the difference between precipitation measured above the canopy and the equivalent inches of combined throughfall and stemflow. The amount of water retained on the equipment was taken into consideration in the calculations. The combined throughfall-stemflow measurements were made after any 24-hour, non-rain period. If the sky cleared after a rainy period, however, the measurements were made as soon as the water held in storage had completely evaporated.

One fall, several sample sites were used to measure interception loss from standing dead grass and the plant residue lying within the ring.

A 1-inch deep black pan evaporimeter, equipped with an overflow, was installed to obtain an index of evaporative potential during breaks in storms. This device could record losses to the nearest .001 inch. Wind speed, air temperature, and relative humidity were also continuously recorded.

Measuring the Grass Stand

Measuring the changes in grass growth throughout the growing season is essential to determine how grass size is related to amount of interception loss. The quantity of grass at each site was measured three or four times during each growing season by the point method of range analysis with a modified point-quadrat frame (Levy and Madden 1933). This frame permitted a sharpened pin to be lowered vertically into the grass on a 25-point grid (*fig. 4*). The height (in inches) of the first hit of each pinpoint on grass foliage was used to determine the average height of the grass (Heady 1957). This measurement represents the height at which a raindrop might first be intercepted. The point quadrat was also used to determine the percent of ground cover (recorded as a decimal percent), and the average number of hits made by the pin as it was lowered through the grass to the ground. The average number of hits was used to estimate the number of layers of vegetation available to store intercepted rain. This value will be referred to as the storage area index (SAI). The grass measurements as well as other work on the sample sites were made from a portable platform to avoid trampling the grass.

Calculating Storage Capacity

The ability of grass to store precipitation against the force of gravity is one of the prime factors affecting interception loss. To investigate the effects of species and growth stage on interception capacity, we grew Blando brome, annual ryegrass (*Lolium multiflorum*), and tall wheatgrass (*Agropyron elongatum*) in 2.25-square-foot flats in a greenhouse. The flats were filled with a light-weight artificial soil (a mixture of perlite and vermiculite),

Figure 4.—*A modified point-quadrat frame was used for measuring the average height of grass at the sample site and the percent of ground cover. It was also used to estimate the number of layers of vegetation available to store intercepted precipitation.*

and the grass was watered with a nutrient solution. The soil surface was sealed with the neoprene latex emulsion. A drain carried off the throughfall and stemflow. The grass in flats was measured at regular intervals in the same manner as grass in the field sites.

The flats—or portable "plots"—were easily moved into a spray booth where the rate of delivery and spray pattern of artificial rain could be controlled. The spray booth was placed in a tunnel where temperature and relative humidity were held constant. Interception storage tests were made at regular intervals throughout the growth cycle of the grass. A ½-inch light rain was applied—more than needed to satisfy the storage capacity of the grass. Storage capacity was calculated as the difference between the applied rainfall and the collected throughfall and stemflow—corrected for water retention on latex and drain surfaces.

Measuring Litter Interception Loss

In this study, grass litter was defined as the dead plant residue, recognizable as to origin, resting above decayed organic matter or mineral soil. Litter interception was measured in 10 20-inch diameter pans equipped with drains and collector cans. The pans were placed at ground level. Samples representative of maximum and minimum amounts of grass litter found in the study area were placed in the pans with as little disturbance to natural arrangement as possible. Decayed organic matter above mineral soil was not included. Measurement techniques of rainfall and throughfall were similar to those for the grass cover. In addition, the pans were weighed periodically before and after each storm to determine the moisture condition of the litter and its drying rates.

Results

Interception Storage Capacity of Grass

Storage area index (SAI) and the average height (in inches) times percent cover (HxC) index were evaluated as measures of interception storage capacity of grass. SAI showed a high variability between observers on the same sampling sites. HxC proved to be a better measure of the storage capacity and was used throughout this analysis. The HxC–storage capacity relationship was evaluated on plots having a relatively high percent cover.

HxC values were converted to storage capacity units by dividing by 100 so their magnitudes would be similar for comparison. The HxC values were found to be an adequate index of grass storage capacity, i.e., HxC of 2 divided by 100, equals 0.02 inch of storage capacity. The interception storage capacity increased rapidly as the grass increased in size—ranging from 0.01 inch to 0.20 inch during the growth cycle for the samples tested in the greenhouse study. The three species tested showed little difference in interception storage capacity (*fig. 5*).

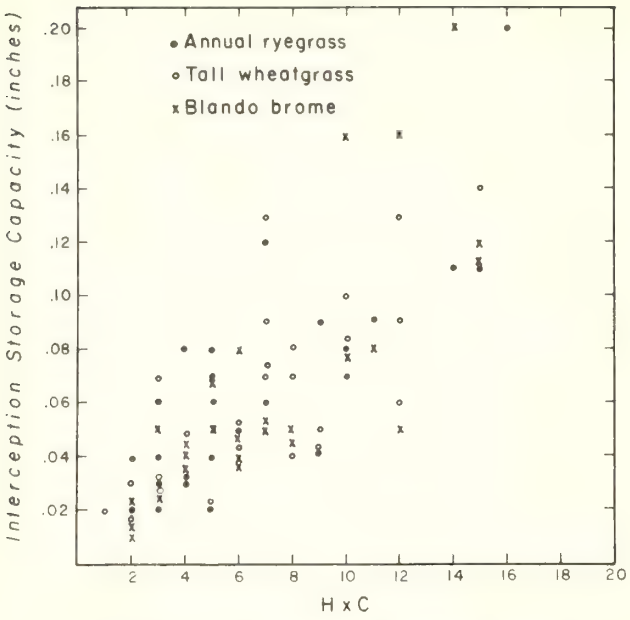

Figure 5.—*Relationship between grass interception storage capacity and HxC index (average height, in inches, times percent cover), San Dimas Experimental Forest, California.*

Interception Loss from Grass

During three field seasons only 25 storms totaling 9.80 inches of precipitation were sampled for grass interception measurements. The largest storm was 2.74 inches. Precipitation in this period was well below normal. And we had the difficulty of establishing a grass stand early enough in the winter to measure interception from the early winter storms. The difficulties of predicting interception loss from the variables measured at the field sites have been summarized by Crouse *et al.* (1966).

To illustrate the relationships between interception loss and stage of grass growth, we developed curves of interception loss as a percent of rainfall for three different stages of grass growth, as characterized by the HxC measurements (*fig. 6*). Individual sample plots were grouped by HxC intervals of 1.0 to 4.9, 5.0 to 11.9, and 12.0 and greater. The largest HxC measurement made during the field study on an individual plot was 17.8. The average height of the grass stand was generally close to the HxC measurements because percent cover was always relatively high. Interception loss from mature chaparral (Hamilton and Rowe 1949) was included for a comparison with the grass interception results.

Interception loss increased as the grass stand developed throughout the growing season. Interception loss from storms 0.30 inch and less was high, and the rate of interception loss from storms greater than 1.5 inches was fairly constant (*fig. 6*). Grass interception loss for storms greater than 1.6 inches is based on only two storms. No large storms were sampled when the grass was in its very early stages of development.

Annual grasses start growth with the first rains of ½ to 1 inch, usually in October or early November. However, growth may be limited by low temperatures, deficient precipitation, or both during the

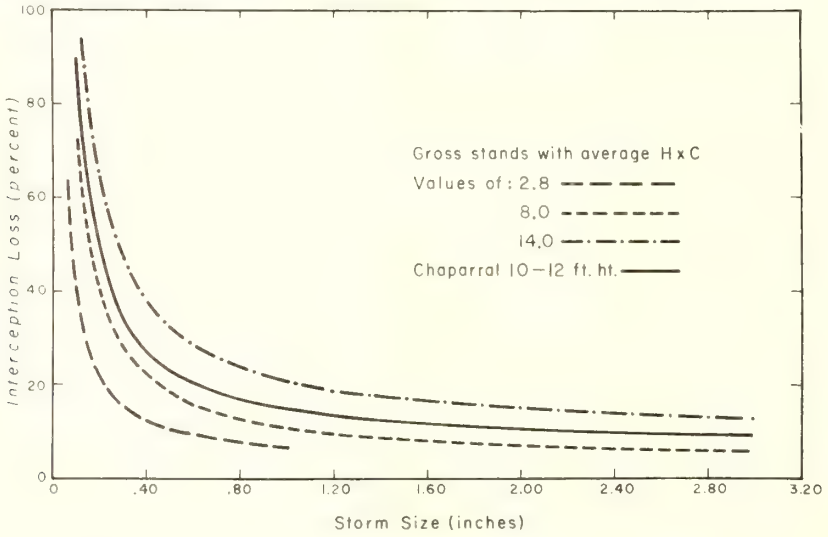

Figure 6.—*Relationship of interception loss to vegetation cover and storm size, San Dimas Experimental Forest, California.*

fall and winter. The plants will usually grow rapidly from February or March until the rains diminish in April or May. Thus much of the annual precipitation falls when the grass is in its lower stages of development. On an average about 67 percent of it falls when grass growth is represented by the HxC = 2.8 curve; 22 percent when growth is represented by the HxC = 8.0, and 11 percent when growth is represented by HxC = 14.0 curves.

Simple regression equations using storm size as the independent variable were computed for each HxC grouping. The relationship between grass interception loss ($\hat{I}_L$) and storm size (P), derived from storms greater than the interception storage capacity as determined by the HxC measurements, are given in *table 1*. For any storms smaller than the interception storage capacity the interception loss should approximate the rainfall input.

The equation derived by Hamilton and Rowe (1949) for estimating interception loss (in inches) from mature chaparral was:

$$\hat{I}_L = 0.062P + 0.083 \qquad (4)$$

in which the first constant is the coefficient of evaporation from the vegetation and the second constant is the interception storage capacity. Their data give standard errors of estimate of 0.044 inch and 0.089 inch for storms under 3.00 inches and all storms up to 11.50 inches, respectively. Comparison of equation (4) with equation (3) in *table 1* suggests that the grass stand approaching maturity has a greater interception storage capacity than the chaparral—0.115 inch to 0.083 inch. In its early stages of development, grass interception storage capacity is considerably less than that of chaparral.

The only way to provide a meaningful comparison between interception losses for grass and chaparral, or for that matter a realistic estimate of annual interception loss, is to apply actual yearly precipitation data to the established relationships on a storm by storm basis. In their work with chaparral, Hamilton and Rowe (1949) measured storms from 0.10 to 11.50 inches in size during an above-average rainfall period. Using the regression equations for grass this far beyond the range of observed data may be risky owing to the small number of large size storms measured, the tendency of the grass to lodge in large storms (especially when tall), and the difference in vegetative structure between grass and chaparral. For storms greater than 3.00 inches the interception loss for grass, as computed by the regression equations, was compared with interception loss as determined independently by extending the curves in *fig. 6* visually at a gradually decreasing slope. For the HxC = 8.0 and HxC = 12.0 curves the difference in interception loss as computed by the two techniques was less than 2 percent. As there were only 18 storms greater than 3.00 inches in the March through October period during the 32 years, these regression equations were used for the comparison. Equation 1 was used only for storms less than 1.00 inch. For larger storms interception loss during the November through February period was computed by extending the HxC = 2.8 curve in *fig. 6* at a slope similar to the HxC = 8.0 curve. As can be seen from *fig. 6* there is only a small change in slope with increasing storm size for the larger storms.

To estimate annual interception losses, precipitation data for a 32-year period were substituted in the regression equations on a storm basis. For storms in November through February, equation (1) or the extended curve representing HxC = 2.8 was used to determine the interception loss. For storms in March, equation (2) was used. For storms

Table 1.--*Equations for estimating gross interception loss (in inches) over the range of storms measured for three stages of grass growth*

Stage of grass growth	Regression equation	Std. error of estimate	r
		inches	
HxC = 1.0- 4.9	$\hat{I}_L = 0.026P + 0.037$ (1)	0.023	0.9967
HxC = 5.0-11.9	$\hat{I}_L = 0.032P + 0.074$ (2)	.027	.9992
HxC =12.0-17.8	$\hat{I}_L = 0.089P + 0.115$ (3)	.040	.9106

occurring in April through June, equation (3) was used. As the grass stand dries and begins to deteriorate in late spring and summer, its HxC values declined below those at maturity. Measurements made in fall indicate the middle curve for grass interception loss (*fig. 5*) would approximate the loss from standing dead grass. Thus for storms occurring in July through October, equation (2) was used. The results are at best, only an approximation of the growth stage of grass in any given year. As pointed out by Heady (1957) and Weihing (1963), growth of annual grass in a particular month can vary greatly between years.

Grass interception loss ranged from 5.0 percent in the 1953–54 Hydrologic Year to 13.8 percent in the 1963–64 Hydrologic Year. The low interception loss of 5.0 percent occurred in a year in which the bulk of the precipitation fell during the grass stage represented by the HxC = 2.8 curve. Seventy-three percent of the rain that year fell in November, when the grass would have been in its lowest stage of development. The high interception loss of 13.8 percent in 1963–64 occurred in a year in which more than 50 percent of the precipitation occurred in March through June, when the grass was in its later stages of development.

The average annual interception from grass over a 32-year period was estimated at 7.9 percent. Chaparral interception loss ranged from 9.5 percent to 19.0 percent, and averaged 12.8 percent.

The interception loss for any individual year will depend on the stage of grass development as influenced by climatic conditions and by the time and size distribution of storms. When the bulk of the precipitation falls in many small storms the interception loss is high. For instance, if only storms under 3 inches during the 32-year period were considered, the interception loss for grass would be about 12.3 percent and that for chaparral 17.8 percent. But, when the bulk of the precipitation falls in a few large storms, this loss would be lower for both grass and brush.

Interception Loss from Litter

A substantial layer of litter lying flat on the soil surface is sometimes found on wildland areas and on ranges in good condition. To obtain an estimate of interception losses from such material, we divided litter samples into two groups: Group 1, averaged 1,650 pounds of grass litter per acre; the samples ranged from 1,000 pounds to 2,300 pounds per acre. Group 2 averaged 5,500 pounds per acre; the samples ranged from 3,500 pounds per acre to 6,900 pounds per acre.

The amount of water evaporated from litter is governed primarily by the moisture-holding capacity of the litter and evaporation potential during and after the storm. The grass litter in group 2 absorbed .06 inch of rainfall, but only slightly over .01 inch of rainfall was stored by the litter in group 1 (*fig. 7*). The grass litter dried rapidly, losing most of its moisture by the end of the second day after a rain. Under natural conditions where the litter lies directly on a moist soil surface these drying curves would be expected to be less steep.

Interception loss increased as grass litter increased but not on a 1:1 ratio (*fig. 8*). Evidently the amount of rain that grass litter retains depends on the arrangement as well as amount of litter. A loosely packed litter layer probably has more effective surface area for water drops to cling to and presents greater opportunity for free air movement and evaporation. Interception losses from small storms were high; those for larger storms ranged between 2 and 5 percent. Litter interception can be estimated from the regression equations in *table 2*.

Applying the 32 years of rainfall data to the regression equations, we found that annual interception loss from grass litter ranged from 2.8 to 8.0 percent, and averaged 4.3 percent. In determining these values, equation No. 6 was used for storms in July through November (representing the period of maximum litter accumulation under natural conditions) and equation No. 5 for storms in December through June. In areas where the rate of litter decomposition is slow, it may be more realistic to use one equation for most or all of a year—depending on the litter amount. Not all grass litter decomposes each year so it may gradually accumulate over time in undisturbed areas (Heady 1956). The time of storm occurrence and the relative amount of precipitation in large or small storms is responsible for the differences in interception percentages from year to year.

The amount of water retained by seeds, dead leaves, and stems of grass accumulated during a 1-year period in the grass interception sampling collars ranged from .02 to .07 inch and averaged .046 inch. These values fall between those for the moisture retention capacities of the two groups of litter studied.

When dried grass decays or is beaten or trampled to the ground by wind and rain, cattle, and other sources, its capacity to intercept rain is then re-

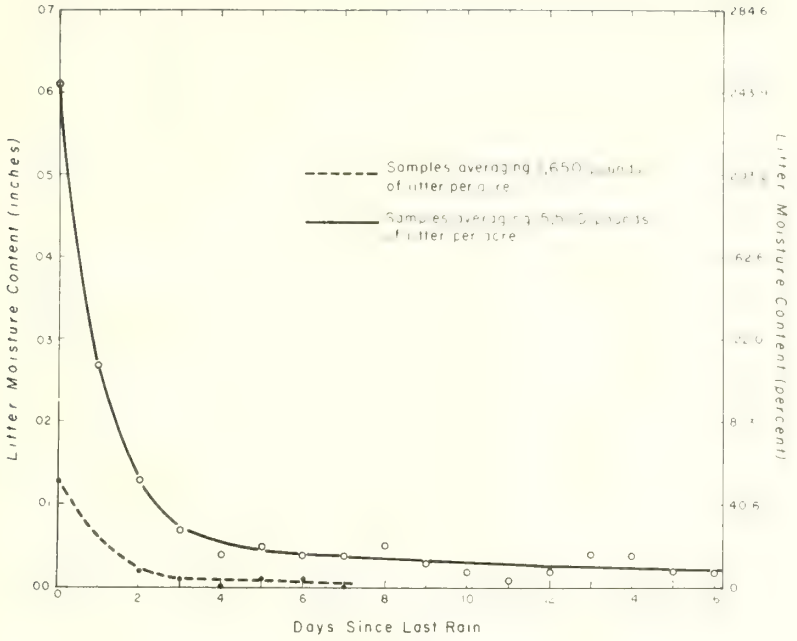
Litter Moisture Content (inches)
Litter Moisture Content (percent)
Samples averaging 1,650 pounds of litter per acre
Samples averaging 5,500 pounds of litter per acre
Days Since Last Rain

Figure 7.—*Moisture content of grass litter dropped drastically with passage of time since wetting. Quantity of litter also affected moisture content. Plotted points represent average moisture content of litter at various time intervals after storms.*

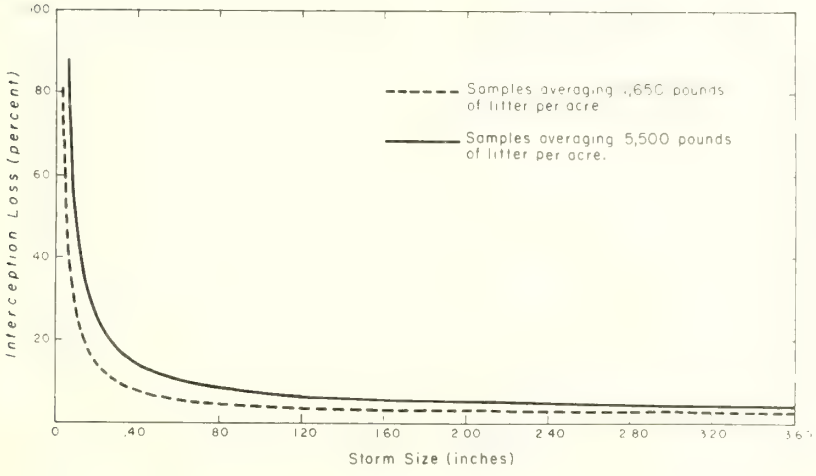
Interception Loss (percent)
Samples averaging 1,650 pounds of litter per acre
Samples averaging 5,500 pounds of litter per acre.
Storm Size (inches)

Figure 8.—*Amount of rain intercepted by grass litter depends on amount and arrangement of litter.*

Table 2.--*Equations for estimating litter interception loss (in inches)*

Litter sample	Regression equation	Std. error of estimate	r
		inches	
Avg. of 1,650 lbs./acre	$\hat{I}_L = 0.015P + 0.025$ (5)	0.013	0.8769
Avg. of 5,500 lbs./acre	$\hat{I}_L = 0.023P + 0.048$ (6)	.021	.7589

Table 3.--*Distribution of annual interception losses for grass, chaparral, and grass litter, San Dimas, Experimental Forest, California*

Interception (percent)	Number of years		
	Grass	Chaparral	Grass litter
2.0 - 2.9	--	--	2
3.0 - 3.9	--	--	7
4.0 - 4.9	--	--	10
5.0 - 5.9	5	--	7
6.0 - 6.9	7	--	5
7.0 - 7.9	6	--	0
8.0 - 8.9	1	--	1
9.0 - 9.9	2	1	--
10.0 - 10.9	1	4	--
11.0 - 11.9	2	5	--
12.0 - 12.9	5	6	--
13.0 - 13.9	3	4	--
14.0 - 14.9	--	2	--
15.0 - 15.9	--	3	--
16.0 - 16.9	--	1	--
17.0 - 17.9	--	3	--
18.0 - 18.9	--	1	--
19.0 - 19.9	--	2	--

duced because it does not have as much surface area exposed to collect water droplets and expose them to evaporation. In annual grass areas, however, grass mulch and litter are the major sources of interception loss during fall and early winter storms.

The average annual litter accumulation for the chaparral types found on the San Dimas Experimental Forest ranged from 419 pounds per acre to 4,079 pounds per acre. The average annual accumulation was 1,323 pounds per acre (Kittredge 1939b).

The total amount of organic matter under the chaparral has been found to range from 6,439 pounds per acre to 46,702 pounds per acre on a dry weight basis. This amount includes all the organic accumulation down to mineral soil. Water retained by the chaparral floor at field capacity ranged from 0.04 to 0.29 inch, amounts considerably greater than for grass litter. These amounts, less the actual moisture content at the beginning of rain, would be subject to evaporation from the chaparral floor and would not contribute to soil moisture (Kittredge 1939a).

Distribution of Interception Losses

The distribution of computed annual interception losses for grass, brush, and grass litter is given in *table 3*. In 18 out of the 32 years used in this analysis, estimated grass interception losses were between 5 and 8 percent. In 19 of the 32 years, chaparral interception loss ranged between 10 and 14 percent.

Discussion and Conclusions

As the grass stand developed throughout the rainy season the amount of estimated interception loss increased. The loss was high for small storms—especially in spring when warming temperatures stimulate grass growth. When precipitation comes in a series of small storms, interception by grass can be quite large. In Hydrologic Year 1963–64, for example, out of a total rainfall of 15.32 inches, the estimated interception by grass was 13.8 percent and by brush, 16.6 percent. Interception loss for large storms, especially if they occur early in the growing season when grass is in its early stages of development, is relatively small. In Hydrologic Year 1953–54, 92 percent of the 24.92 inches fell in seven storms. The calculated interception loss from grass was 5.0 percent and from chaparral 10.9 percent.

Grass in its later stages of growth may give similar or even higher interception values than mature chaparral. In California, however, annual grass is in these stages for only a few months at the end of the rainy season. Chaparral vegetation, being ever-

green, can intercept a fairly constant amount of rainfall the year round. This characteristic accounts for its higher yearly interception values.

In years of average precipitation (26 inches), an estimated 1.3 inches in gross interception losses could be saved by converting from brush to grass at San Dimas. This estimate does not consider possible differences in litter interception. An average precipitation year is a theoretical term computed arithmetically. Actually in only 8 years out of 32 at San Dimas did the annual precipitation amounts fall between 22 and 32 inches. The savings would have ranged from 0.31 inch to 2.30 inches in the hypothetical cases evaluated in this paper. They would probably be even greater if the litter components of grass and chaparral are included. Besides reducing the rate of soil evaporation (Rowe 1955), the litter layer protects the soil from erosion and helps to retard surface runoff. Thus the value of the litter layer may outweigh the amount of interception loss under many conditions.

Cattle grazing reduces interception loss from grass by reducing the quantity of vegetation and thus, its interception storage capacity. The interception loss on grazing lands could be estimated by using the interception loss relationship which represents the grass conditions at the time of rain storms. A savings in soil moisture at the same time also would be realized because of the reduced transpiration by the shorter grass plants (Mitchell and Kerr 1966).

The net water loss to the watershed from grass or chaparral interception can only be surmised. Interception losses from non-transpiring surfaces, such as dead grass or brush stems, would certainly result in a net water loss to the watershed. The net water loss to the plant-soil-water system may not be as high as the gross interception measurements reported in this paper, but its amount is undoubtedly significant in the redistribution of precipitation.

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Forest Landscape Description and Inventories —

a basis for land planning and design

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Forest Landscape Description and Inventories

a basis for land planning and design

R. Burton Litton, Jr.
Associate Professor, Landscape Architecture
University of California

Summary Report on Cooperative Agreement
Supplements No. 80 and 96 F. S. Master Contract
No. A5fs-16565 between

Pacific Southwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
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R. Burton Litton, Jr.

Berkeley

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DURING much of the past 4 years, I have been studying the nature of the forest landscape as a visual entity as part of a cooperative study of the Forest Service and the University of California. The objectives of this study have been:

— to recognize the impact of the landscape as a critical ingredient in recreation use and travel,

— to devise means of recording and expressing the landscape resource,

— to consider the relationships between resource management and the visual resource, and

— to pose areas of future research concerned with better and more comprehensive use of the landscape.

This report summarizes conclusions about what to look for and ways of recording landscape attributes. The approach is from the discipline of design, but throughout the study it has been evident that designers must depend upon other disciplines to validate their impressions and carry out their proposals. I hope this discussion of the scenic content of the landscape will contribute a common vocabulary for inter-disciplinary effort and aid those who must inventory scenic resources. We seldom all mean the same thing, or see the same thing when discussing or observing the landscape.

Recognition of the Scenic Resources

Description and inventory of the landscape are best achieved by use of a limited number of terms. To help define these terms, we must turn to sketches and photographs. But even these are at best a poor substitute for the three-dimensional reality of the landscape. Furthermore, reliance on graphic means of explanation recognizes that the design vocabulary is a general one, and that there is no systematic design terminology for exclusive application to the landscape. Besides limiting the number of words selected for definition and application, then, we must accept another limitation — an implicit one — that the landscape is considered as a visual, physical entity and not as a state of mind or abstract emotional quality.

Calling the landscape a scenic resource assumes that it has esthetic value. From this assumption, it follows that the discipline of design can provide a particular point of view as to what constitutes the landscape, what affects visual perception of it, and how it may be categorized.

FACTORS OF SCENIC ANALYSIS AND OBSERVATION

Six factors affect the landscape as it is seen or affect the observer as he looks at the landscape.[1] They are distance, observer position, form, spatial definition, light, and sequence. All of these factors are variable; they may change with the passage of time, and some may be changed voluntarily through manipulations which affect the resource and the observer. Three — form, spatial definition, and light — are concerned essentially with the landscape per se, and man can do little or nothing to alter them. The other three — distance, observer position, and sequence — are concerned essentially with the observer in relation to the landscape, and we can alter or manipulate these relationships.

DISTANCE

If we think about opportunities to view landscapes, we can conclude that it is possible to establish an optimum proportion between the scale of the landscape, or segments of it, and distance from viewpoint. Perhaps we cannot agree as to what constitutes "optimum proportion," but a review of possible relationships should be helpful.

It may appear irreverent to suggest that the problem is one of ability to "see the forest for the trees." Another problem is whether the observer can select distances from which a particular objective may best be seen. A pedestrian or boater has a chance to select viewing distances; the motorist does not. Careful planning of roads or trails, however, can consider routes which set a series of distance relationships, or zones, chosen to enhance anticipated visual harvesting of scenic resources.

A conventional way of designating distance zones is to divide the landscape into a series of three planes or grounds: foreground, middleground, and background.

[1] *Litton, R. Burton, and Twiss, Robert H. The Forest landscape: some elements of visual analysis. Soc. Amer. Foresters Proc. 1966: 212-214. 1967.*

Figure 1 — Distinct foreground, middleground, and background planes. (Sierra Nevada from White Mountains, Inyo National Forest, California.)

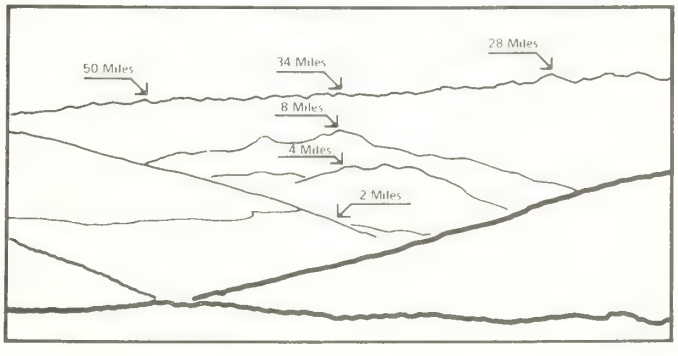


Figure 2 — Distance diagram for figure 1.

This division provides a convenient isolation of parts for analysis or comparisons (figs. 1, 2). The terms are derived from painting or pictorial arts, in which they indicate that a painting may be divided into these planes whether the illusion of space created within the frame is a few feet or many miles.

In describing landscapes, however, it is a useful simplification to establish distance zones by designated measurements. Then the visual significance of a road or waterfall, for example can be examined and its relationship to landscape appraised within a fixed frame of reference. Accordingly, three zones are proposed:

	Near Boundary	Far Boundary
Zones:	- - - - - - - - - - - - miles - - - - - - - - - - - -	
Foreground	0	¼ - ½
Middleground	¼ - ½	3 - 5
Background	3 - 5	∞

These ranges of zones are arbitrary in that no allowance is made for atmospheric, seasonal, or diurnal variations, except through discrimination in choosing the boundary. But I have found these distances applicable during months of field work in the National Forests and environs of California, Oregon, Washington, Arizona, New Mexico, Georgia, and Florida in the years 1964 - 1967. Throughout this report these distance ranges are used in considering what may be seen.

Foreground

Foreground has a simplicity in designation not to be found in either middle or background: the simplicity of the observer's presence. The observer is in it. The amount of detail which can be seen is a function of time and speed, but maximum perception of detail can only occur at close range. Surface patterns of bark, juxtaposition of tree trunks, the nature of the understory vegetation, the roadway and its edges are examples of what might be seen here. The observer is able to relate himself to the size of the parts, such as an individual tree, and he begins to sense a scale relationship between himself and the landscape. Aerial perspective is absent or insignificant in foreground, and the intensity and values of color are to be seen in maximum contrast, contributing to the sense of presence. Another contribution to sense of presence is that wind motion in trees or on grass can be seen in this close-in area but seldom beyond. Other sensed experiences are also a part of this intimacy: the sounds, smells, and tactile experiences that are most acute here.

This intimacy gives rise to two possible disadvantages. The foreground may mask what lies beyond. And attention to detail may detract from the landscape matrix of which the foreground is but the frontal part. In either case, the context of the larger landscape may be lost, or at least momentarily so. Yet these possibilities can also be considered an advantage. Involvement with foreground provides one means of developing a sequential visual experience with travel over time.

Middleground

Middleground, or the intermediately distant landscape, is most critical. Here the linkage between parts of the landscape may be seen. Within the foreground we see a single hill, but middleground distance offers a chance to see that a series of hills are joined together into a range, or that a drainage pattern becomes apparent through its support of a particular plant community. The emergence of shapes and patterns, and the visual simplification of vegetative surfaces into textures should take place here. It is in this range that the joining of parts can be clearly seen. Consequently the middleground aspect can often best show whether man-made changes rest easily or uneasily on the landscape.

Aerial perspective in the middleground distance, softens — or "grays down" — color contrasts. The simplification resulting from this softening effect of aerial perspective, makes the middleground a visual foil for the greater complexity and detail of foreground.

Middleground skyline silhouttes (and the middleground per se) become an interesting combination of detail and generalization. Wind motion along the middle distant skyline can be seen, but elsewhere at this range it disappears. Tree species often can be distinguished by their form against the sky.

Middlegrounds are especially critical not only because they tend to dominate the view, but also because they may include large acreages of forest resources. In

a landscape inventory made on the Sierra National Forest, for example, middleground made up about two-thirds of the total visual corridor.

As a summary, an analogy to archeological exploration might be drawn concerning middleground distances. Aerial observation from a distance has revealed patterns of historic occupation, such as Roman roads in England, which could not be seen on the ground even though detailed evidence indicated their existence. So observation at middle distance can reveal landscape units or articulation between units which cannot be understood at close hand.

Background

Simplification is background's distinction. The distant landscape or the expansive view reduces form to simple outline shape and removes any (or most) sense of surface texture or detail; the open sky adds an ethereal quality. This simplification may make either foreground or middleground stand out more clearly.

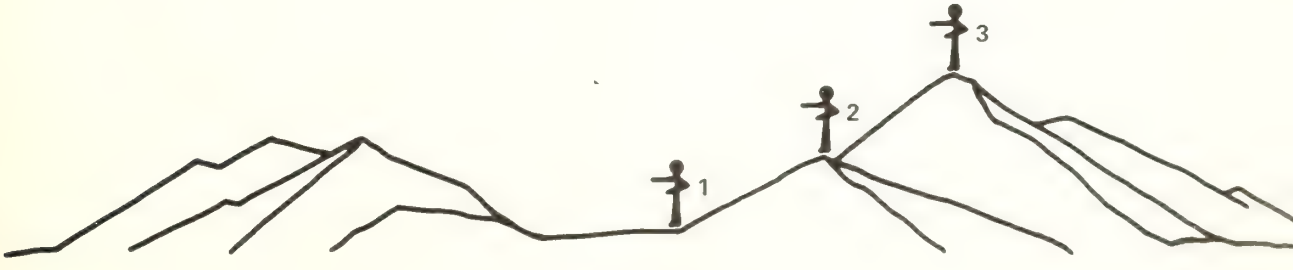
Aerial perspective, which flattens and minimizes color contrast, is the key explanation of background simplification. As distinctions between color hues diminish in the background, they tend to be replaced with values of blue or gray. Only gross patterns stand out: dendritic drainage defiles, the margins of forest, land masses in juxtaposition.

Skylines or ridge lines against other land surfaces are the strongest visual elements of the background. This repetition of the smaller linkages of the middleground again supports the extending, expanding nature of distant landscape.

Finally, a dilemma should be mentioned. We must recognize that as observers travel, the background may become middleground or foreground. The concept of grounds is a static one and the observer is mobile. Nevertheless the mapping of distance effects as grounds is an obvious, and simple, way to provide planners and designers the information they need for application to specific situations. They can see where modification of the landscape may lead to incompatible relationship of forms or to undesirable artificiality. And they can see where changes may enhance the natural landscape — by opening new vistas or by revealing details that aid comprehension of the local ecology, geology, economy, or history.

OBSERVER POSITION

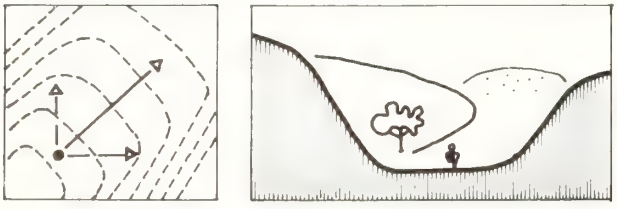
Observer position is a term adopted in this report to describe the location of the observer as he looks upon a visual objective, particularly with regard to being below, at the same level as, or above the visual objective. These possibilities will be referred to as (1) observer inferior, (2) observer normal, and (3) observer superior as indicated by the following sectional diagram:



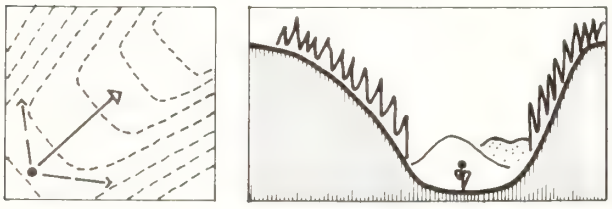
Observer position is preferred to terms like "view point" or "station point," which lack emphasis upon the viewer and his relationship to the landscape. It is an important factor in landscape description because it is subject to manipulation. Observer positions may be consciously selected, for example, in the routing of a proposed trail or road. Considering this factor, then, promotes a broader purpose than concern for only the road itself.

Observer Inferior

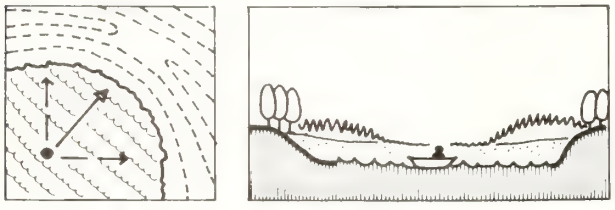
Observer inferior position exists when the observer is essentially below the surrounding or nearby landscape. Saying "essentially below" is necessary to be realistic; there is literally always something to be seen below eye level. Of the three possibilities, this one is most restrictive with respect to closure and distance. Contour plans with sketch diagrams can demonstrate certain of these restrictions. They show a progression from very tight enclosure with foreground distance to slight enclosure with background distance:



Case 1.
Most Restrictive, possible conditions:
a. Small lake or valley station point
b. Uphill aspect of ravine or canyon
c. Foreground distance limitation



Case 2.
Intermediately Restrictive, possible conditions:
a. Valley or lake station point
b. Downhill aspect of intermediate or distant landscape
c. Middle or background distance limitation.

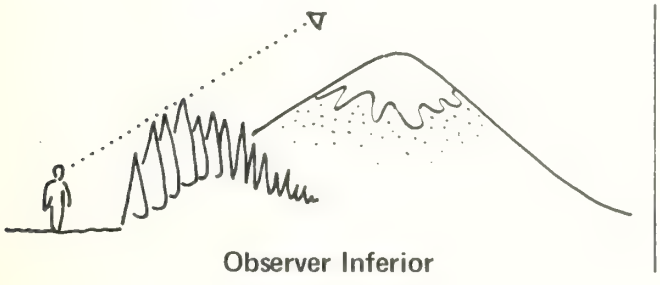


Case 3.
Least Restrictive, possible conditions:
a. Broad valley or wide lake station point.
b. Aspect from central point or floor
c. Middle or background distance limitation.

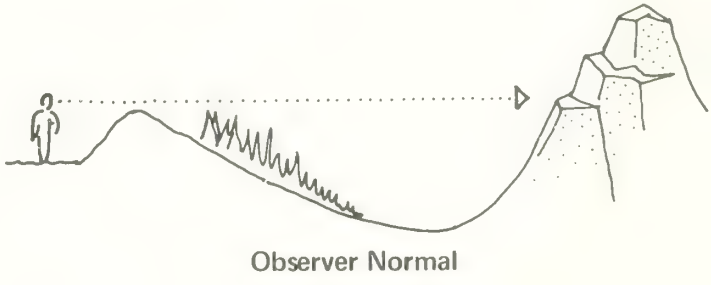
Some effects of the observer inferior position are concerned with the visual blockage which occurs because of intervening screens of plants, trees, or land forms. They hide certain features or surfaces, mask relationships between segments of the landscape, or obscure a terminal objective. Two-dimensional diagrams suggest emphasis on blockage of vertical angles of sight, but screening effects should be thought of as in the round. We have the greatest control over screening effects with the observer in inferior position. Observer inferior suggests direction of attention to foreground detail, the emphasis of small parts, and the screening of segments.

Figure 3 — Observer inferior position foreground distance restriction (Canyon de Chelly National Monument, Arizona.)

Figure 4 — Observer inferior position, middle-ground distance restriction. (Mt. Shinn, Sierra National Forest, California.)



Observer Inferior

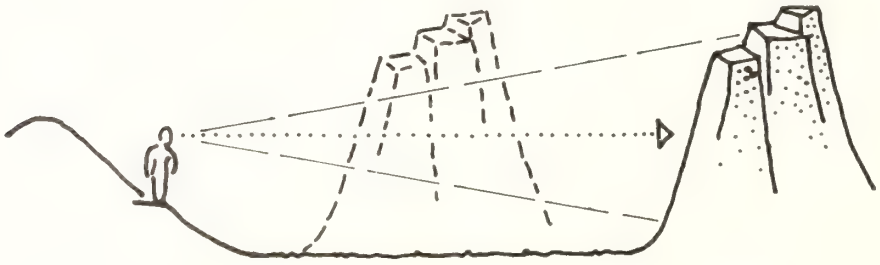


Observer Normal

Observer Normal

The observer normal position obtains when a level line of sight generally coincides with the dominating elements of the landscape. Although the sky is usually a significant part of any landscape view, observer normal generally concentrates attention on the solid or water elements of the landscape rather than the sky. In certain respects, the observer normal position is inclusive because it incorporates some characteristics of both inferior and superior. Consider two cases in which observer position is normal, objective remains the same, but distance and spatial order differ:

Figure 5 — Observer normal position, foreground distance restriction. (Bridgeville Post Road, California.)



Case 1 Case 2

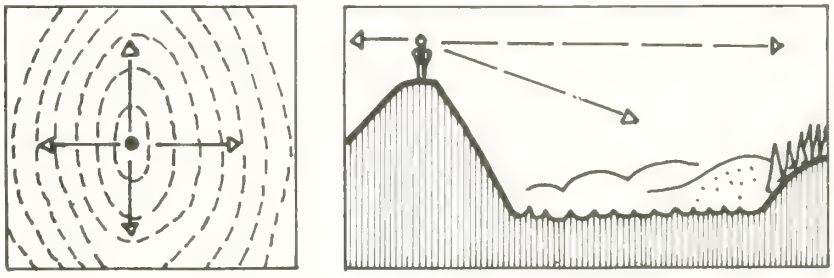
Case 1 resembles observer inferior; Case 2, observer superior. Since the diagram has no scale, it can serve to demonstrate that the greater intervening distance and space of Case 2 could be interpreted as representing either middleground or background, but observer normal will tend to stress middleground. Screening effects should be less with observer normal than with observer inferior, but should result in more visual blockage than will occur with observer superior.

Since the observer normal location can be called "a hybrid between upper and lower parents," it can be thought of as the most comprehensive single choice of viewpoint if choice must be exercised. It aids orientation as the overviews of the superior position do, yet it maintains close contact with enclosing walls as the inferior position does. And this contact, in turn, contributes to recognition of space.

Observer Superior

The classic expression of observer superior is that of a mountain summit or ridge top overview in which maximum opportunities are present for distant views, and an opportunity exists for orientation to the gross structure of the landscape. Observer superior is least restrictive with respect to limitations in enclosure, screening, direction, or distance. It has a characteristic of detachment akin to the detachment of the aerial view. Such a sense of being suspended can result from slope drop-off parallel to lines of sight, tending to diminish the sense of support or platform under the observer, and from the fact that the distant landscape provides the dominant objective. Two plan and sketch diagrams portray possibilities:

Case 1.
Least Restrictive,
possible conditions:
a. Peak-top station.
b. 360° view potential, ahead and to all sides.
c. Background distance observable.



Case 2.
Moderately Restrictive,
possible conditions:
a. Ridge edge station.
b. 180° or more view potential, rear blockage.
c. Background distance observable.

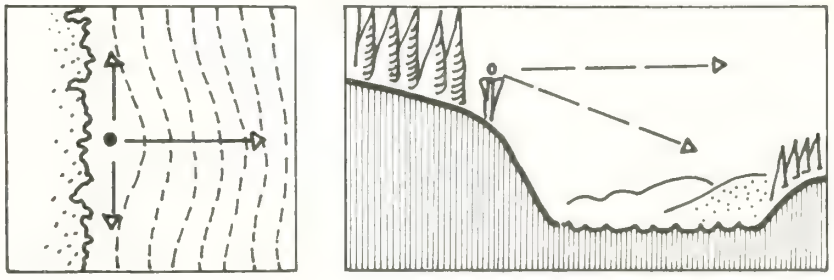
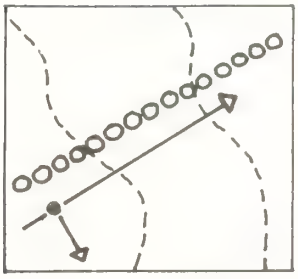
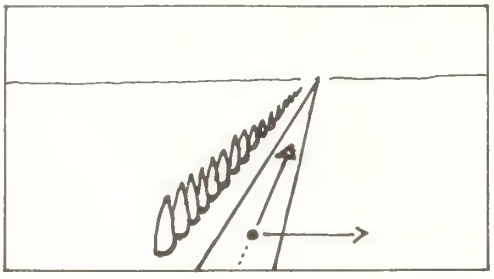


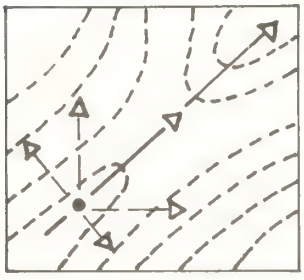
Figure 6 — Observer superior position, foreground emphasis, horizon at middle-ground distance. (Canyon de Chelly National Monument, Arizona.)

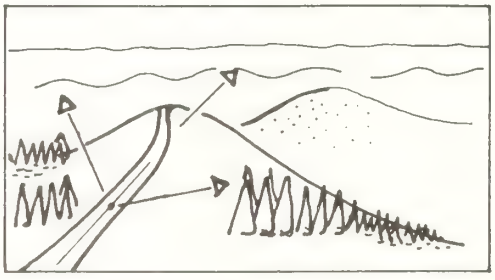
Observer superior minimizes visual blockage. Views down upon the landscape will permit a maximum though generalized revelation of content. Achievement of the observer superior position often results from a sequential climax. It supposes a journey or climb which originates in the lowlands, works its way through intermediate terrain, and finally reaches a high point. But a sense of climax can be achieved in many situations that do not involve such a climb. As the sightseer follows a road or trail, three kinds of possibilities exist: tangents, horizontal curves, and vertical curves. Such possibilities can be exploited in road layout or trail design as well as in landscape analysis.



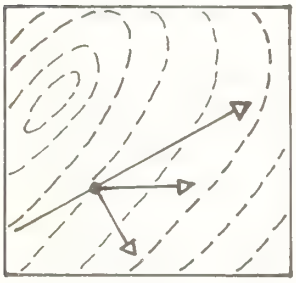


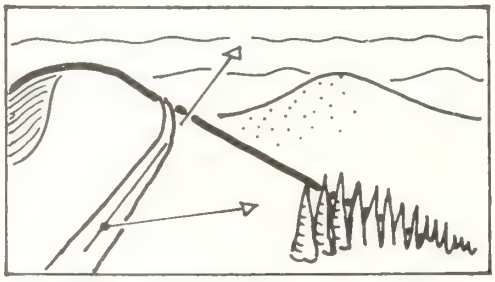
Case 1A.
Tangent, possible conditions:
a. Frontal focus, related to speed and enclosure.
b. Side view to 90° either or both sides of center line.



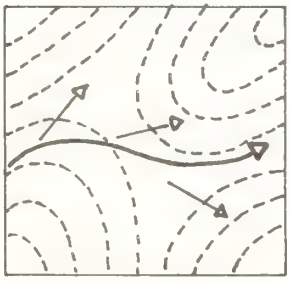


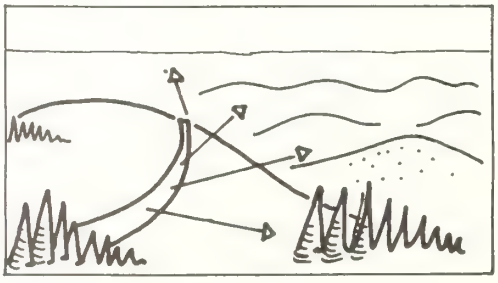
Case 1B.
Ridge Tangent, possible conditions:
a. Frontal focus
b. Side views to 90° each side.





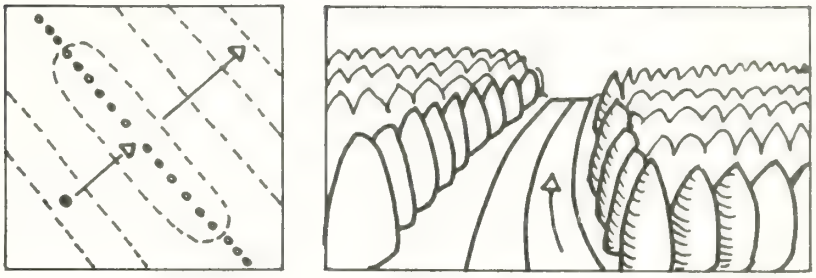
Case 1C.
Sidehill Tangent, possible conditions:
a. Frontal focus.
b. Downhill side view to 90°, uphill restriction.



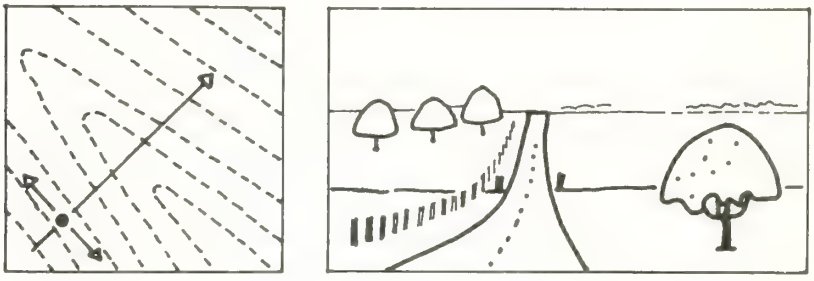


Case 2.
Horizontal Curve, possible conditions:
a. Shifting frontal focus
b. Downhill view series emphasis, to 90° to the side.
c. Uphill side view restriction.

Case 3A.
Vertical Curve, peak-hill crest:
a. Frontal blockage
b. Side views to 90° each side, enclosure allowing.



Case 3B.
Vertical Curve, sag-valley bottom
a. Frontal blockage
b. Side views to 90° each side, enclosure allowing.



FORM

Form in the landscape is primarily topographic form and refers to the three-dimensional convex elements of the geomorphic base. A list of a few geological terms will indicate some specific kinds of forms that are known through common experience and should suggest a variety of different images:

range	butte (mesa)	escarpment
mountain	knoll	crag
cinder cone	dome	cliff
hill	crest	island
bald	ridge	spit

Figure 7 — Isolated form, contour distinction against horizontal base. (Church Rock, Moab, Utah.)

Figure 8 — Skyline silhouette, surface variations of cover. (Toll House Hill, Highway 168, Sierra National Forest, California.)

Contrast is the necessary condition to reveal a dominant form, and the contrast may result from isolation, size, contour distinction or silhouette, or surface variations.

Individual land forms within ordinary landscapes will be found to demonstrate some, if not all, of these significant contrasts. Although Church Rock (fig. 7) may seem to dominate by size in a photograph, its isolation and distinctive silhouette also set it apart. Local place names often point to other examples of such contrast: "Lover's Leap," "Mt. Baldy," "Rock Slide," "Eagle Rock." Mount Rainier would be an example of size domination over adjacent landscape; yet its distinguishing characteristics also include those of contour outline and surface differences. Both contour distinction and surface variations may direct the observer's attention toward steep slopes or other features (fig. 8).

Figure 9 — Tree as isolated form. (El Dorado Hills, Highway 50, California.)

Figure 10 — Vegetative patterns, shapes overlayed on form. (Upper Twin Lake, Sawmill Ridge, Toiyabe National Forest, Bridgeport, California.)

Vegetation may be the chief source of contrast due to variations in surface. Trees as individuals or in limited groups, particularly in the presence of plains or placid land forms, can themselves be primary forms in the landscape (fig. 9). But the vegetative cover more often appears as a pattern of two-dimensional shapes laid over the three-dimensional base (fig. 10). "Shape" is used here to imply two-dimensional meaning — a differentiation from "form." Vegetation obviously is not two-dimensional, but it gives that visual impression, appearing to be a thin skin when compared to vertical differences in the land forms it covers. Vegetative cover may also strengthen the visual contour of land form (fig. 11). The margins or edges of dissimilar vegetative types are the significant contrast lines where drainage patterns, slope, or implication of soil changes may be seen. Riparian vegetation, as an example, can obscure a water course yet reinforce land form

Figure 11 — Hill forms with edge definition by trees. (Shady Rest, Highway 168, East of Clovis, California.)

through contrast with the plant cover of drier upland slopes. Escarpments and similar abrupt surfaces which are essentially barren, or likely to be so, also achieve some of their visual strength through contrast with adjacent plant-clothed areas.

In addition to shape overlays (or patterns) of vegetative cover over form, the textural nature of trees and other kinds of plants can provide a sense of scale to elements of form. Our experience leads us to recognize tree size in relationship to the human body; the presence of trees, or their simplification to texture in the distance, can, therefore, provide a clue as to the scale of land forms and their distance away. A grass-covered knoll or a slick granitic dome could be thought of as abstract in absolute size unless something of familiar size were present to provide a yardstick for scale. Some degree of familiarity and astuteness on the part of the observer is implicit, however. Environmental circumstances that produce dwarfism in trees, an unusually large species such as *Sequoia sempervirens*, an unusually large land form, or other conditions could confuse the observer's ability to judge scale.

A first step toward recognition of dominant topographical forms would be to check topographic maps, looking for abrupt changes in contour, isolated departures from general patterns, or margins of vegetation. Listing such discontinuities will show where visual attractions may be expected in the landscape.

SPATIAL DEFINITION

Spatial definition within the landscape or landscape spaces refers to the three-dimensional concave elements of the geomorphic base, vegetative enclosure, or a combination of both. This concept denotes limited or bounded space rather than boundless expanse. Again a list of a few geological terms will indicate some specific kinds of spatial definition and should suggest a variety of different formal images:

basin	ravine	dale
valley	gorge	meadow
canyon	cirque	glade
crater	pocket	swale

There can be a corollary between spatial definition and form but one cannot predict which may dominate.

Spatial definition in a landscape varies greatly. It may be vague as compared to architectural space with its precise floor, wall, and overhead ceiling planes. Outdoor spatial definition is nonetheless determined by floor and wall planes and is distinguished by the absence of overhead enclosure; only rarely is there any sense of tree canopy or cloud cover providing a ceiling to the landscape. Concavity is the common denominator of landscape space, but elaborate variation is possible in the nature and degree of enclosure. Four sources of variation may be cited.

First, the proportion of wallheight to floor expanse. The higher the walls and the lesser the floor extent, the greater the spatial definition; the lower the walls and the greater the floor extent, the lesser the spatial definition.

Second, the nature of the enclosing walls and of the floor. Walls and floor can add to or detract from recognition of spaces: Walls may be sheer rock cliffs or gentle wooded slopes; the bounding edge may be continuous or interrupted; floor may be a flat grass plane or a complex surface of grass, chaparral, erratic boulders, and scattered trees. Special mention should be made of lakes and ponds. These

Figure 12 — Space — small scale, positive and simple enclosure. (Ely Meadow, Shaver Lake, Sierra National Forest, California.)

particularly commanding base planes or floors are normally expected to be contained within a positive vessel of space. Not only is impounded water the only truly flat and potentially simplest surface to be expected in the landscape, its changing response to light and weather gives it what might be termed a life of its own.

Third, the configuration of the floor as it meets a boundary of trees or earth face. A small meadow of simple elliptical outline is more immediately visualized than a large dendritic valley with central inclusions. Again water should be singled out. Its edge, as the junction between liquid and solid materials, delineates an extremely strong and lucid shape or floor configuration.

Fourth, differences in absolute sizes. Landscape spaces may differ in scale yet present a common quality of enclosure (figs. 12, 13, 14). Again, reference to place names may suggest variations of both size and quality of spatial definition: "Grand Canyon," "Long Meadow," "Green Valley," "Glen Aulin," "Pocket Canyon."

We also need to consider how the observer best senses spatial definition. The total extent of a landscape can usually be understood most clearly when the observer is high on the lip of an edge wall, looking down upon the floor and walls. Though valuable for orientation, such knowledge is not to be confused with a more realistic sense of enclosure. The maximum expression of spatial definition can be expected with the observer on the bottom of the space (on the floor plane) and adjacent to some part of its vertical enclosing surface.

Figure 13 — Space — intermediate scale, discontinous enclosure. (Broder Meadow, Sequoia National Forest, California, U. S. Forest Service photo.)

Figure 14 — Space, large scale, positive enclosure. (Slinkard Valley, Monitor Pass Road, Toiyabe National Forest, California.)

Scale, as relationship sensed between the size of an observer and his surroundings, can be most clearly seen within a well-bounded space. A sense of scale is due essentially to limitation: limitation of area or extent, limitation of elements to be seen, and limitation of competition for the observer's attention. Scale tends to be an abstract quality, but it becomes more tangible when spaces are created through timber cutting, range clearing, or vegetation-type manipulations. The idea of "opening-up" a vista could be approached more objectively if conceived with the understanding that accompanying changes of spatial definition and scale are fundamental changes. Citing examples of made-spaces is not to be confused in importance with the coordinating function of large-scale spatial definitions which provide a basic part of the landscape's visual framework.

LIGHT

An understanding of light and its effects is essential to predict the visual consequences of land-use decisions. We tend to overlook the importance of illumination of the landscape. That is, we recognize that the quality of daylight will be whatever occurs at a given time, and that we are powerless to change it. But the effects of light change profoundly during the course of a single day and during the course of the seasons. The nature and magnitude of those changes must be understood if we are to analyze their role in masking or emphasizing natural or man-made changes in the landscape itself. We can seek understanding in terms of color, distance, and direction.

Color

Color, the basic manifestation of light, is expressed in two ways: through hue and through value. Hue is that quality of color through which an object is called red, green, yellow, etc. This is likely to be the commonly expressed meaning of "color." Value is that quality of color through which an object is called dark or light — its tonal quality in terms of resemblance to black, white, or an intermediate gray. Separation of hue from value may seem more academic than realistic, but both are important to landscape perception.

Chromatic color (resembling pure hues seen separated in a rainbow) is a rarity in the landscape and becomes significant because it is unique. It is usually seasonal or temporary: the brilliant greens of spring foliage or grass; the strong yellows, oranges, or reds of autumn foliage; the brilliant blues of sky or water associated with clarity of atmosphere and water. Saying these examples represent pure or chromatic hues is inaccurate. What they do represent is heavy saturation of certain hues which become visually dominant in relation to the grayed hues more common in nature. Such modified hues are due to the presence of white, black, or other colors and could be exemplified by designations such as:

"spruce green" — (black modification)
"chaparral green" — (gray or complementary hue modification)
"earth brown" — (black, gray, or complementary hue modification)

Climatic or other conditions may influence observation. Flat lighting of an overcast day will enable subtleties of color to be seen without competition of shadow, but over-all intensities and contrasts will be diminished. Riparian plants are often distinguished by greater color brilliance than plants in drier, upland areas.

Leaf texture and surface reflection will also contribute to changes in color response of vegetation.

Color-value effects in the landscape may be said to predominate over color-hue effects through being more common either in point of time or in areas of coverage. Although exceptions are inevitable, the following kinds of contrasts in color value are common enough to be called rough rules:

1. The sky is invariably lighter than earth elements, clouds being infrequent exceptions.
2. Grasslands are lighter than tree or shrub cover.
3. Soil is likely to be lighter than tree or shrub cover, or only infrequently darker.
4. Disturbed soil has a distinct value contrast compared to undisturbed soil or plant cover. In the Sierra Nevada, disturbed soil is generally lighter.
5. Hardwoods are lighter than coniferous trees.
6. Overcast sunlight or flat lighting diminishes value contrasts; intense or full light increases value contrasts.

These listed sources of contrast in color value will be seen to have particular application to margins or edges between materials of varying reflective or absorptive surface. This application in turn, points to correlations with form, shape, and their degree of distinction.

Distance

Aerial perspective affects both color hue and value of the landscape in the distance. The effect results from scattering of light rays so that objects farther away have a more blue or gray cast, and the contrasts of light and dark diminish toward uniformity. This effect was mentioned as influencing judgments concerning distance.

Direction

Direction of light in striking the surface of the landscape can be described as back light, side light, and front light. Back lighting is particularly associated with early or late daylight, and front to side lighting with mid-day; but if the observer is able to change his position with respect to the sun, any direction may be possible (fig. 15).

The orientation and gradient of land surfaces also will modify directional relationships. North-facing slopes are more likely to be obscured by shade and shadow than south slopes. East or west slopes of comparable gradient can expect a similar amount of sun or shade but at opposite times of the day. The order of least to most anticipated direct light on slopes would then be: (1) north, (2) east and west, (3) south. In turn, this relationship suggests a progressive order to opportunities for acute observation.

Back lighting, when the sun is in your eyes, makes details of the landscape and its surface become obscure. Top or outside edges are emphasized. Surfaces are obscured by long blanketing shadows, and often by a pool of bright light that sets up a barrier between observer and distant objects. One dramatic exception to the masking shadows cast by opaque objects in back lighting is the luminescence of light passing through translucent objects, particularly exemplified by thin broad-

leaf foliage (fig. 16). Back-lit hardwoods in autumn color, especially in the presence of surrounding dark conifers, will appear to contain their own source of illumination.

Side lighting and front lighting may well occur at the same time unless the surfaces of the landscape are so simplified that only a single or dominant face is presented to the light (figs. 15-18). The major difference is that side lighting produces a greater sense of modeled three-dimensionality than front lighting. In front lighting, shadows are shorter, shading falls away from the observer, and more surface tends to be in full light. Hence an apparent flattening or simplification of surface affects our ability to detect variations. Photographers have long recognized these effects and recommend side lighting rather than front lighting to bring out modeling and texture.

Figure 15 — Influence of direction of light; A, backlit panorama, 8:30 a.m., edge emphasis, minimum detail; B, sidelit panorama, 12:30 p.m., distinct patterns at 5-6 miles; C, frontlit panorama, 4:30 p.m., distinct patterns at 5-6 miles. (Bucks Summit, Plumas National Forest, California.)

Direction of lighting seldom negates skyline silhouettes. When seen by side or front light, silhouettes maintain the maximum contrast of any landscape features because of the contrasts between solid elements and the fluid, filmy color of the sky. Contrast is also maintained by back lighting except for the special case of the corona in which the intense brightness impairs visual acuity.

We have seen that shadows help emphasize form. Long shadows interspaced with full light can be particularly effective in revealing the modeling of form, space, and shape. Obtuse angles of incidence are implied in this situation. Lower intensities of light may also contribute to the sense of form and space through more highly developed shading. Higher light intensities produce reflected rays and tend to burn out nuances of shading.

Is there any single "best" lighting of outdoor scenes? Probably not, because a comprehensive understanding of light influences should recognize a full range of possibilities over an extended period of time. If extended observations are not possible, then side lighting should be taken as the criterion, for it may contribute to the clearest single impression of landscape. Despite time-dependent changes, and vagaries of weather, there are regularities in the effects of light. If understood, these regularities can be used by the alert resource manager to dramatize landscape elements. Such applications include routing roads or trails, locating overlooks, or selecting sites for interpretive programs.

Figure 16 — Aspens, transmitted light against shadow. (Lassen National Park, California.)

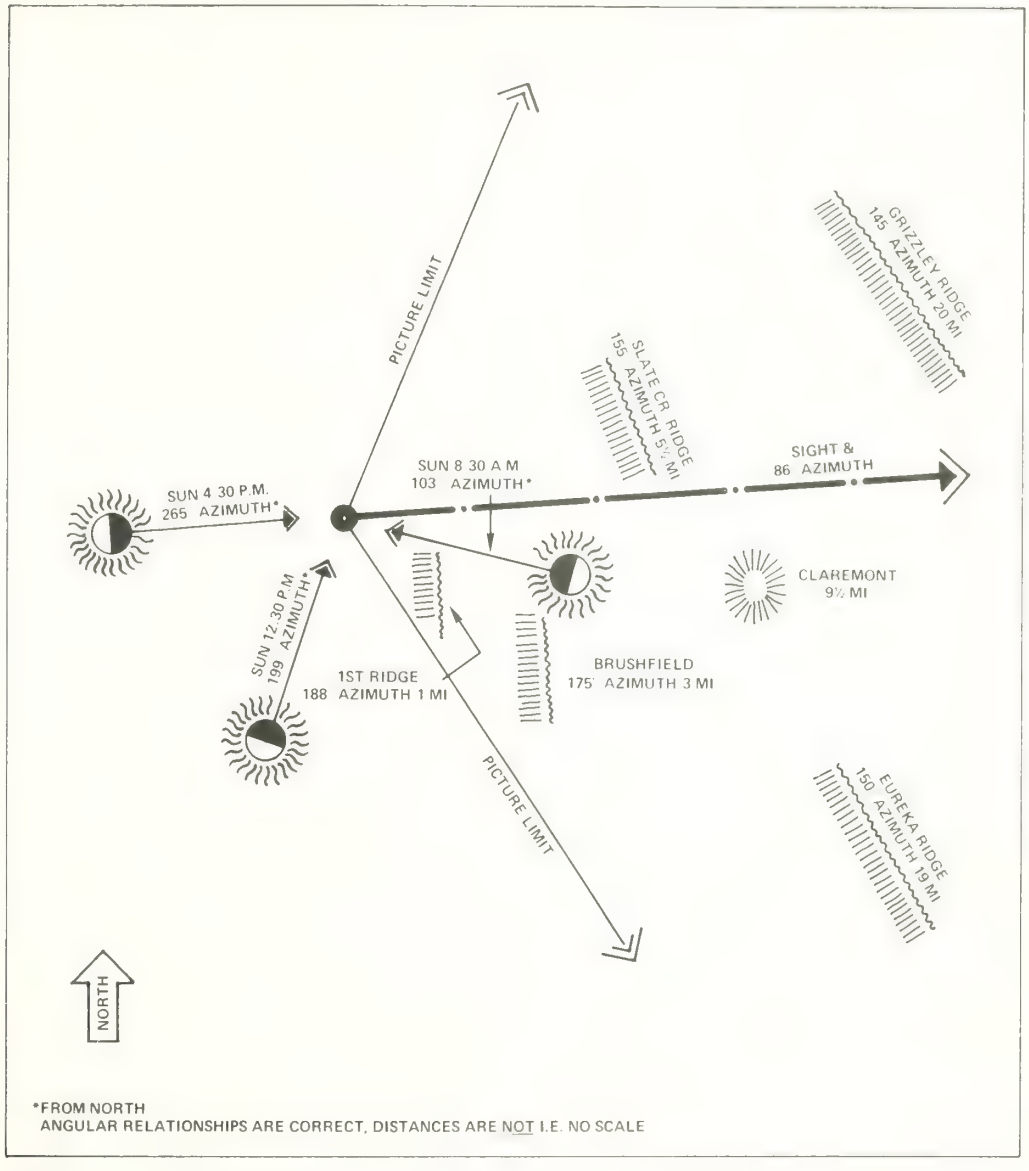
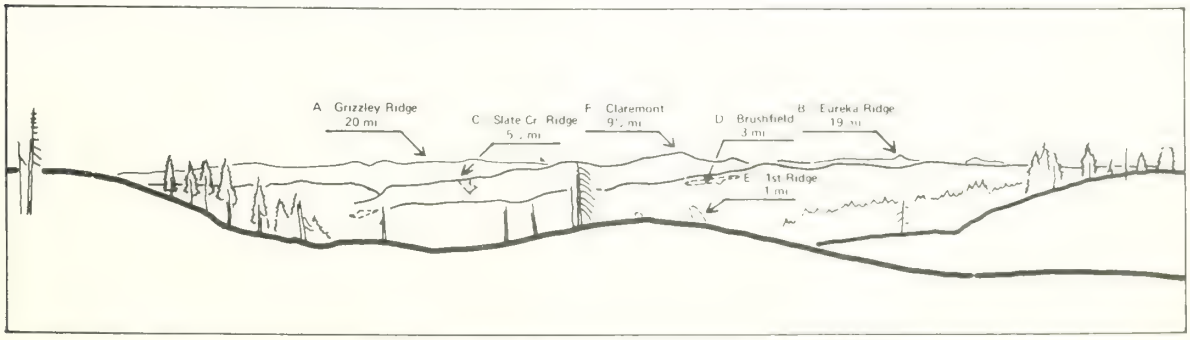


Figure 17 — Plan diagram of photo figure 15.

Figure 18 — Distance diagram for photo figure 15.

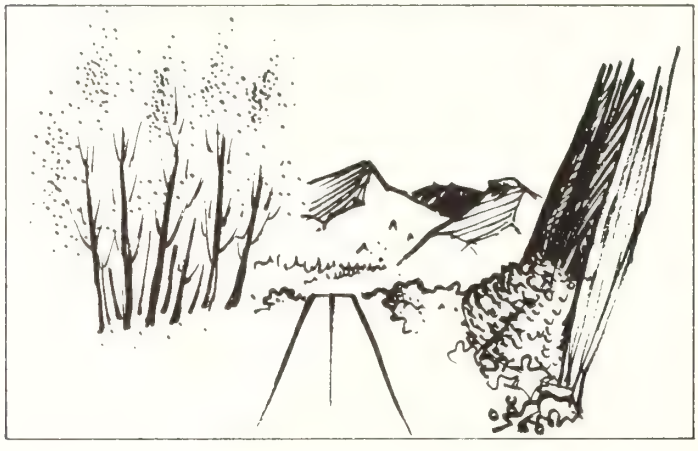


SEQUENCE

Sequential visual experiences — the progressive interplay of forms, distances, spaces, lighting, and observer position — can enrich appreciation of the landscape (fig. 19). Thus analysis of sequence along a road or trail enhances landscape description. Even though only part of the total may be seen at a given moment,

Elapsed time: 1¼ minutes

Elapsed time: 1 minute



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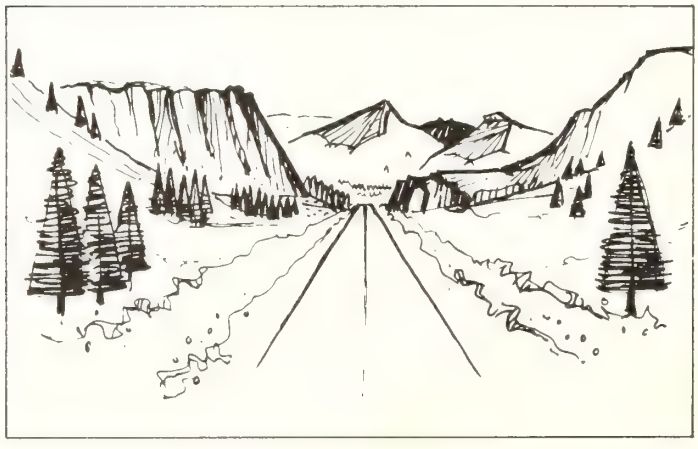


Figure 19 — Sequential views, 1¼ minutes at 60 m.p.h. — read up. (Devils Gate Pass Sketches, Toiyabe National Forest, California.)

memory and anticipation can supply flanking parts of a continuum made up of parts which can be seen to contain some amplitude of contrast. Recording contrasts in landscape attributes, then, is a most promising way to bring sequence into description of the landscape resource along routes of travel. The record can be useful not only in analyzing existing routes, but also in layout of proposed routes.

Historical gardens as diverse as those of medieval Japan and baroque France were designed with recognition of principles of sequential changes in purpose, form, space, and scale. In this way designers provided the visitor with the maximum opportunity to experience change and contrast within the boundaries of the garden. From study of the Japanese garden as a source of planned spatial experiences, Thiel has developed notational methods of recording the sequential factor for application to contemporary design.[2]

His methods, and those of other students of the landscape, were drawn upon for the inventories discussed later in this report. In addition, I have found it helpful to work with a check list of possible sources of contrast (see appendix) which may be systematically considered in recognizing and recording the sequential changes. Time and distance traveled should be included in the record.

COMPOSITIONAL TYPES

Recognition of compositional types that recur in the landscape provides a visual framework for observation. The word "composition" is used here with the meaning derived from Runes' definition of composition: "The putting together and organization as in work of art; or the product of such organization."[3] This is not to say that the landscape is defined as a work of art, but rather that it can be seen to have certain characteristics of a work of art. Seven compositional types are proposed:

1. Panoramic landscape
2. Feature landscape
3. Enclosed landscape .
4. Focal landscape
5. Undergrowth landscape
6. Detail landscape
7. Ephemeral landscape.

The first four may be called fundamental and are of larger scale; the second three may be called secondary or supportive, of smaller scale or transitory in nature. Each has a visual framework which is basically consistent despite great variations of dimension, character, and clarity.

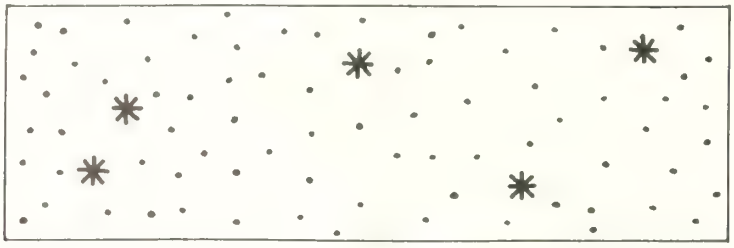
Diagrams will be used to abstract the visual design compositions in an attempt to aid identification and — together with photographs — to suggest possible variations within the types.

In classifying scenic resources by compositional types, we often find that the perimeters of the visual framework break down or cannot be clearly seen. What do we call the landscape continuum which lies between types? The tentative answer is to suggest that there is a landscape matrix or general continuity for a given geomorphic province or region. Within such a region, the compositional types may be thought of as occurring in nodes. Or we can specify that only the most visually significant examples of the types clearly constitute the scenic

[2] *Thiel, Philip. A sequence-experience notation for architectural and urban spaces.* The Town Planning Review *32(1): 33-52. 1961.*

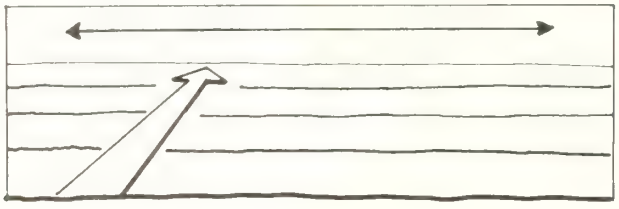
[3] *Runes, Dagobert D. and Harry G. Schrickel,* The Encyclopedia of the Arts. *1,064 pp. New York: Philosophical Library. 1945.*

resource. But one important point needs to be made: the landscape matrix has a visual role comparable to that of background foil whereby contrast should reveal the landscape compositional nodes more clearly. A diagram may explain this concept — stipple indicating the matrix and asterisks indicating occurrences of particular types:



PANORAMIC LANDSCAPE

We tend to think of a panorama as the composition to be seen from an ocean liner: a 360° view limited only in the continuous line of the horizon. On land, a panoramic landscape may often be limited to about 180°, a response due to being at the edge of such a composition and to peripheral vision:



The line emphasis is upon horizontality as the dominant characteristic, and the general attitude of the major lines of the composition seems essentially perpendicular to the lines of sight. There is little or no sense of boundary restriction. The inference of considerable distance is present, and foreground or middleground impose no limitation on the horizontal composition of panoramic landscapes. As an expression of distance and openness, the sky and cloud formations assume important, and at times dominant, roles of modifying the stabile character of horizontality.

The 126° panoramas from Bucks Summit (fig. 15) are examples, and others abound at oceanside, on plains, and from ridge tops (figs. 20, 21, 22).

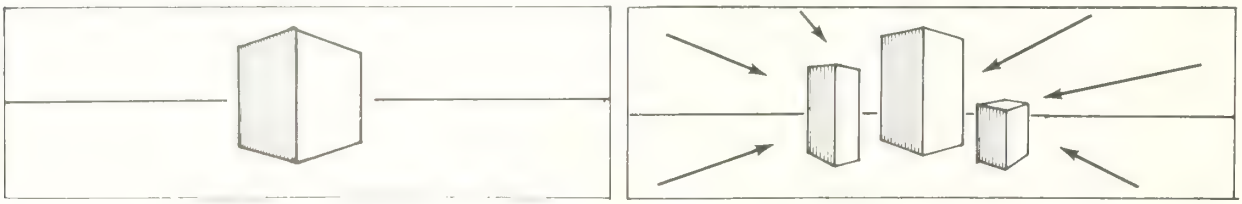
Figure 20 — Ocean panorama — abstract expression, observer eye level 8 ft. above surface. (Drakes Beach, Pt. Reyes National Seashore, California.)

Figure 21 — Flat plain panorama, observer eye level 8 ft. above surface. (River Camp, San Joaquin Valley, California.)

Figure 22 — Ridge top panorama, observer superior, cloud-skyline emphasis. (Lewiston area, Trinity National Forest, California.)

FEATURE LANDSCAPE

A landscape dominated by a distinctive feature is a powerful aid to orientation of travelers. Throughout history landmarks have served this purpose, and recognized landmarks are often given descriptive names that identify the feature landscape. This compositional type is one of the most diverse because it can be found at so many different scales — from monumental imposition to intimate local identity. "Mount Rainier" suggests a feature of grand proportions. "Lone Pine" suggests a significant local feature. Diversity may also stem from differing forms or groups of forms. Sometimes a group of forms may function as a single unit predominating over the surrounding landscape: "Twin Peaks," "Ten Lakes," "Three Gossips."



In the feature dominated scene, lines of visual tension or attraction should converge upon the single element or upon the grouped elements. Equally important, surroundings should be definitely subordinate. The size of a landmark in relation to its surroundings (its scale), the distinction of its configuration, and its juxtaposition with adjacent forms or planes establish the area of subordinance. We see, therefore, that a feature has a sphere of influence that needs to remain intact or that can tolerate only certain changes without deterioration of the composition. No rules can be offered as to what might constitute a damaging change, but identifying and plotting the margins of the visual envelope around a feature is the first critical step toward assessment of what can or cannot be allowed. And no generalizations can be drawn about compositional structure of feature landscapes, but examples can suggest a range of possibilities (figs. 23-26).

Figure 23 — Dominant cone form, massive scale. (Mt. Shasta, Shasta National Forest, California. U. S. Forest Service photo.)

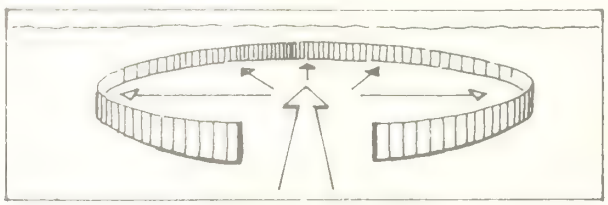
Figure 24 — Dominant cone form, medium scale, contrast to base plain. (Steptoe Butte, Washington.)

Figure 25 — Dominant vertical form, small scale, vertical consistency. (Whitakers Forest, adjacent to Kings Canyon National Park, Sierra National Forest, California.)

Figure 26 — Dominant sinuous form, color value and motion contrasts. (Tuolumne Cascade, Yosemite National Park, California.)

ENCLOSED LANDSCAPE

An outdoor space in which unity is dependent upon recognition of bowl-like form or the continuity of sides around a base plane, is an enclosed landscape:



The lines of visual attention should first be drawn into the central void of an enclosed landscape and secondarily encompass the side walls, ricochetting about the edge definition of the floor if it is conspicuous (figs. 27-29). Water's edge is such a conspicuous definition, and the surface plane of a lake encircled by earth forms is one of the most sharply drawn examples of enclosed landscape. Even this sharpness, however, can break down if the expanse of floor plane is so great as to cause the off-shore wall to become insignificant or invisible. In general, expanse or distance becomes the visual enemy of the enclosed landscape, and it may be replaced gradually or sequentially with a panoramic composition.

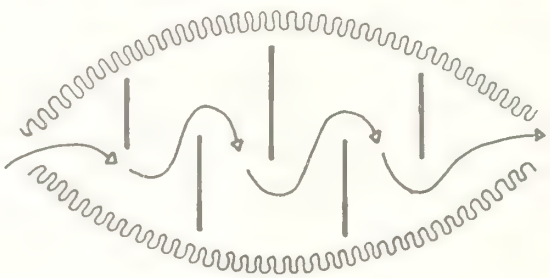
The enclosed landscape is a contrasting counterpart of the feature landscape but often may be less dramatic since the total structure of a space suggests a more subtle quality than that of feature domination. Subtlety of enclosure may be a

Figure 27 — Enclosed landscape, grass base plane, small scale. (Quail Flat, Sierra National Forest, California.)

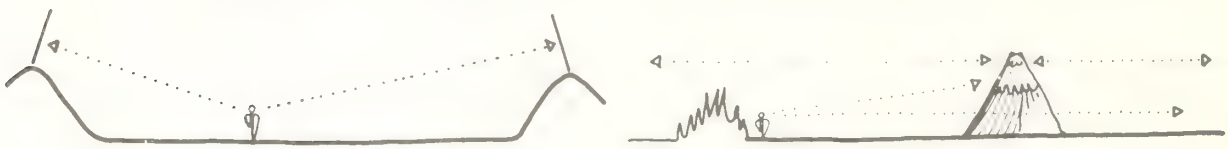
Figure 28 — Enclosed landscape, lake base plane, medium scale. (Woodys Lake Chattahoochee National Forest, Georgia.)

Figure 29 — Enclosed landscape, meadow-riparian zone base plane, large scale. (Leavitt Meadow, Toiyabe National Forest, California.)

matter of variation in the nature and the scale of the walls and floor. Or visual barriers inside the space may obscure parts of enclosure walls at some points of observation:



Although as diverse in scale and definition as feature landscapes, the enclosed landscape usually has rather more definite boundary. Enclosure tends to be a physical barrier, whereas feature domination constitutes only a sphere of visual influence:



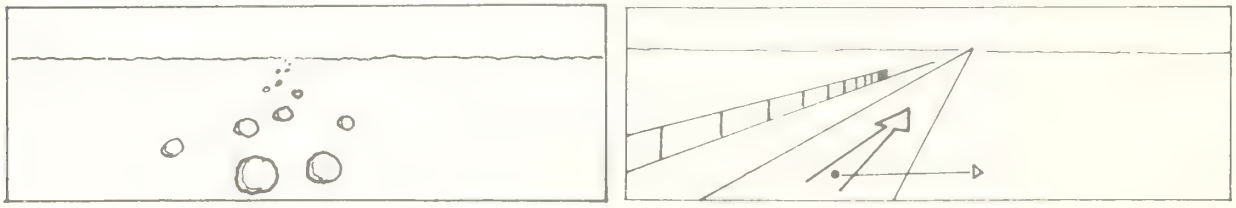
Many intergrades can exist between compositional types, and though we need not explore them all, two seem especially appropriate at this point. First, a minor feature or landmark may become significant within the embracing framework of a space (fig. 30) because of the visual restriction of the enclosure. Second, the side-by-side occurrence of feature domination and enclosed landscape is a dominant-subordinate relationship; the feature provides identity — and often a descriptive place name (fig. 31).

Figure 30 — Minor features within restriction of small enclosed landscape. (Richard Russell Scenic Highway, Chattahoochee National Forest, Georgia.)

Figure 31 — Dominant feature ridge as partial side of enclosed landscape. (Cathedral Range-Tuolumne Meadow, Yosemite National Park, California.)

FOCAL LANDSCAPE

A series of essentially parallel lines or of elements seen in alignment create a focal landscape. Parallel lines or aligned objects, in appearing to converge to a focal point, guide the eye toward their apparent origin:



Observer position must be such that lines of sight parallel lines of the focal landscape. The degree to which the composition may seem to converge toward a point is highly variable (figs. 32-35). Four possibilities are common in the forest landscape:

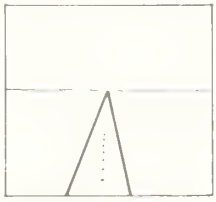
Figure 32 — Focal landscape, stream course with self-closure terminus. (Shasta River, Trinity National Forest, California.)

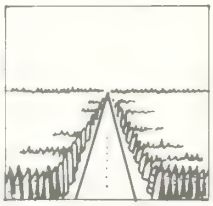
Figure 33 — Focal landscape, aligned elements, feature terminus. (Virginia Lake Road and Conway Summit, Highway 395, Toiyabe National Forest boundary, California.)

Figure 34 — Focal landscape, creek course within a panorama. (Bodie Road, south to Mono Lake, California.)

Figure 35 — Focal landscape, road aligned on feature terminus. (Tuolumne Pass Road, Cathedral Peak, Yosemite National Park, California.)

1. Point convergence



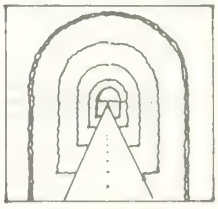


2. Feature terminus

3. Portal

(At vertical curve)

(Tunnel-portal)



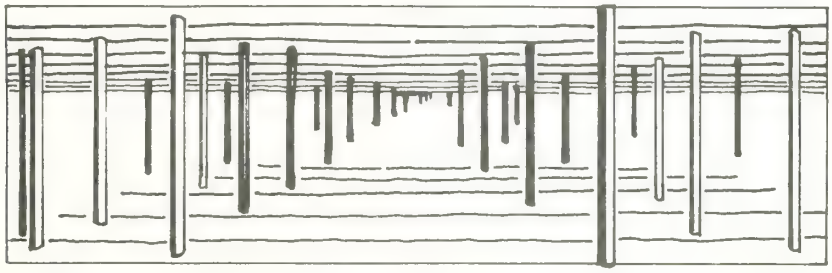
4. Self-enclosure

(At horizontal curve)

Both point convergence and feature terminus may occur with or without side enclosures; that is, either may be overlaid on an open panoramic landscape or can occur as corridors on a flat plane. Portal or self-enclosure compositions can occur only in the context of enclosed landscape. Line and spatial characteristics of each should be apparent in the above diagrams. A stream course or a road tangent are the most likely places to look for the focal landscape. Perhaps the most commanding or effective focal composition occurs when a landscape feature is present as a visual terminus.

CANOPIED LANDSCAPE

Canopied landscape refers to the compositional character of the landscape to be found under the crown cover or within the forest. Such compositions tend to be of relatively small scale. Leaf canopies create ceiling planes, and perspective closure of tree stems or screens of understory shrubs and young trees or land forms develop side enclosures:



The scale and the detail within overhead and side restriction mean that a canopied landscape can be most readily seen and comprehended by an observer on foot. The automobile driver has insufficient time to see details adequately. He is also removed from them. And his attention is continually directed ahead.

Nevertheless, we should recognize that road channels within the forest represent the closest contact that many sightseers have with the forest. More accurately, the road (or trail) guides and controls observation. There are three basic possibilities. First, the broad, open corridors of major highways and freeways — four lanes or more, divided or undivided. Second, the medium corridors of primary or secondary roads designed for moderate speeds. Third, the small corridors or undergrowth tunnels of minor or minimally improved roads.

The first two tend to minimize forest contact. Their wider clearing channels push back the tree edge, and higher cuts and fills divorce the road from the forest floor. Seldom, if ever, can a leaf canopy make a ceiling over the roadway. Superhighways, particularly multiple-lane undivided roadways, impose the greater impacts.

Minor or minimally improved roads for use at slower speeds allow tree edges to become, nominally, the road edge. Lower cuts and fills maintain contact between road and forest floor. The tunnel enclosure of leaf canopy over the road can be a practical possibility.

Transferring the characteristics of the slower-speed road to high speed roads has little chance to succeed. Lane division and use of broad median areas can help maintain contact with forest stands. But we should recognize that each road type imparts a different scenic quality to the stand — more light or less; more enclosure

or less; more closeness or less. One is not better than the other. Each offers a difference which should be retained for variety and contrast (figs. 36-39).

To make the most of the automobile observer's opportunities to see or sense the forest within which he travels, we can watch for and map three sources of contrast: forest type changes and differences; crown class and stand variations, and spatial variations — corridors and tunnels. Only the most marked contrasts will register with the more rapidly moving observer. The more subtle ones are reserved for the pedestrian.

Forest type changes generally provide obvious visual contrast. A change from hardwood to conifer type should be apparent to any observer. But differences between conifer types, for example, can be so subtle as to escape notice except by the most astute or well-informed observers. Then changes in stand or crown character may provide visual impact. Descriptive terms from forestry are rich in implications of contrast — open and closed crown canopies, even-aged and uneven-aged stands, dominant and suppressed crown classes.

A good example of such contrast is the distinct junction of two forest types — a black oak-Jeffrey pine mixture and a pure red fir stand along Highway 168 (fig. 40). The gross visual impact is that of an open, sunny space adjacent to a tight, shaded corridor. An abrupt margin emphasizes differences between the types. Other contrasts reinforce the image. In early spring (when the photograph was taken) the color impression of the oak area is bronze-buff; that of the fir corridor, blue-green. Crown closure is about 40 percent in the oak-pine; 85 percent in red fir. Shrubby ground cover in the open oak-pine contrasts with grass in the fully stocked fir stand. The canopy, or ceiling plane, is lower in oak-pine.

Figure 36 — Canopied landscape, tree tunnel as spatial definition. (Napa Valley, Highway 29. Photo by Bernard Shulte.)

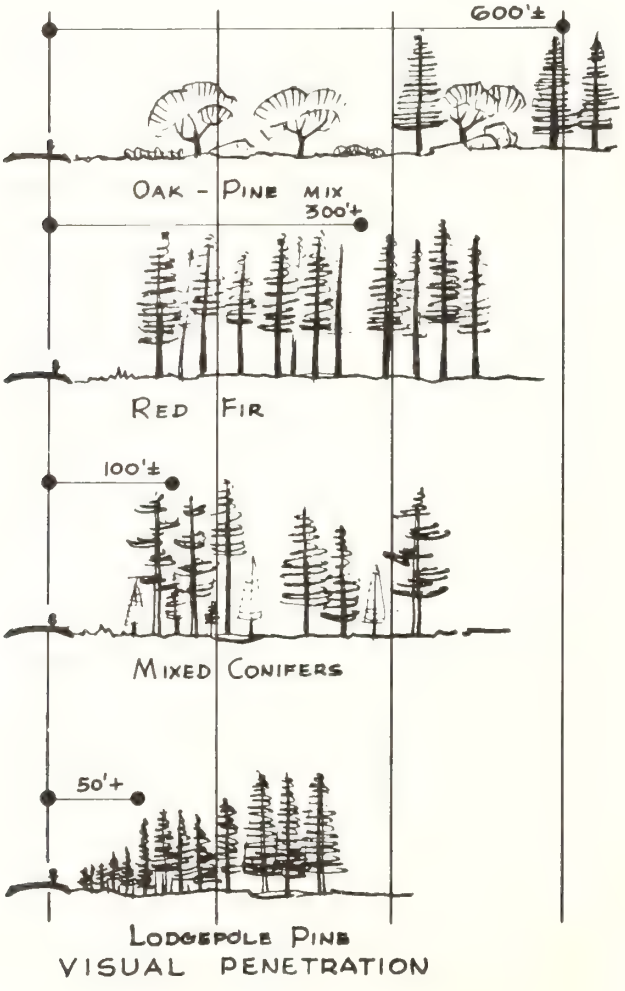
Figure 37 — Canopied landscape, forest corridor as spatial definition. (Highway 168, Shaver-Huntington Lakes, Sierra National Forest, California.)

Figure 38 — Canopied landscape, pure conifer type. (Highway 36, Van Dusen River, near Grizzley Creek, California.)

Figure 39 — Canopied landscape, mixed hardwood type. (Anna Ruby Scenic Area, Chattahoochee National Forest, Georgia.)

Figure 40 — Canopied landscape, junction between dissimilar forest types and stands. (Highway 168, Shaver and Huntington Lakes, Sierra National Forest, California.)

Estimates of visual penetration can point up the spatial character of forest stands. In the inventory of scenic resources along Highway 168, for example, the depth to which it was generally possible to see was estimated at several points along the 16-mile route. Averages of these estimates in four forest types permit useful comparisons:



VISUAL PENETRATION

It was possible to see twice as far into the oak-pine as into the red fir. Visual penetration into mixed-conifer and lodgepole pine types was much shorter. Both these types included all age classes of trees. In mixed conifer, the different species occupied virtually all of the air space with overlapping crowns, and the stand was fully stocked if not overstocked. In lodgepole pine, young trees, doghair thick, overstocked soil along the road edges; older trees beyond this young growth formed several stories.

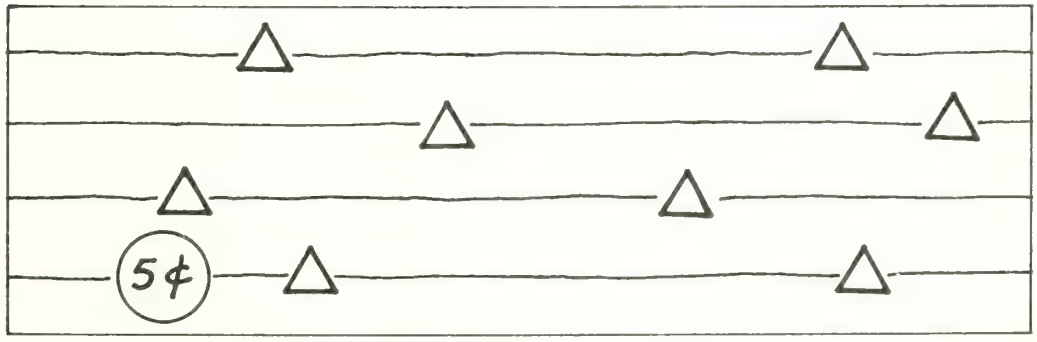
Such simple observations of stands that flank the road remind us that road width does not end visually where grading and clearing stop. More important, the observations pin down variations in relative enclosure that travelers can be expected to see — and hence help identify and describe the canopied landscape.

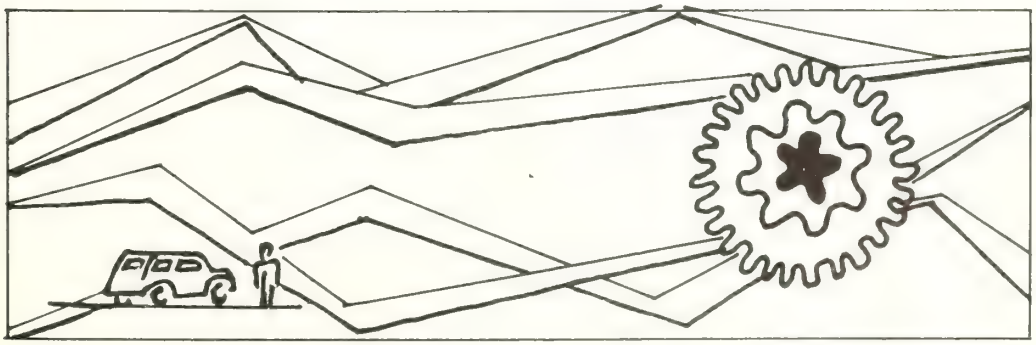
Subtle as this compositional type is, it can provide variety within other landscape types and it can be manipulated, as by judicious thinning, to enhance contrasts — or even to create them. Appreciation of the canopied landscape may require a good deal of knowledge. But this requirement is more an opportunity than a handicap. It is a chance for interpretation that makes a journey meaningful.

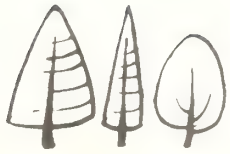
DETAIL LANDSCAPE

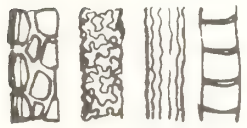
The minor details, or minutiae, of a single view also may contribute meaning to a visual experience. Taken together, the minutiae often form a compositional type which as a sample of the larger scene, deserves special attention. Like the canopied landscape, this detail landscape requires a pedestrian pace and an eye for special amenities.

The detail landscape may be a segment of an overall pattern; it may be an angular composition with a single dominating form in contrast:









But a diagram is not much help in explaining the nature of this compositional type. We are concerned primarily with scale rather than with the disposition of elements into a design composition. The possibilities of form, shape, and pattern and their arrangement are infinite.

What distinguishes this compositional type, then? It is consistent in being a typical expectation of the general landscape within which it exists. A segment of the rain forest floor cannot be confused with a bit of desert pavement. Ansel Adams and Edward Weston have included in their work photographs of details which demonstrate an essence of place. And throughout history, details from nature and the landscape have been a prime source of suggestion to design. More than a mere sample, the detail landscape can be a symbol.

Observers may differ in their affinity for minutiae, but a conscious effort to look for symbolic details will seldom go unrewarded. Plants — from lowly fungi, lichens, and mosses to individual shrubs and trees — display forms, shapes, and patterns in unimaginable variety. Plant parts repeat environmental themes, or set up counterpoint, in bark, leaves, flowers, and fruit. Rock deposits and outcrops, weathering patterns and water — in creeks, seeps, and trickles — all these contain design elements which combine to reflect in microcosm the larger landscape. Color, inseparable from the nature of details, may at times be a dominant characteristic. Choice of detail is dependent on scale, which may vary from an area of a few square feet to a cubic volume of much larger surfaces. An observer's ability to concentrate attention sets the limits. Whatever the choice of visual attention, the detail landscape (figs. 41-45) is a representative specimen taken within the restriction of pedestrian concern.

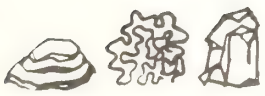


Figure 41 — Detail, reticulated pattern, weathered sandstone. (Salt Point Ranch, Fort Ross, California.)

Figure 42 — Detail, rosette patterns, sand bar plants. (Dry Creek, Healdsburg, California.)

Figure 43 — Detail, sinuosity, environmental distortion. (Sonora Pass, Stanislaus National Forest, California.)

Figure 44 — Detail, rock and water forms. (Dana Fork Tuolumne Creek, Yosemite National Park, California.)

Figure 45 — Detail, angular outcrop and spheroid tree form. (Mt. Diablo State Park, California.)

EPHEMERAL LANDSCAPE. Recording Methods

The ephemeral landscape could be called the landscape of the double take – its significance or content may be overlooked. It depends on transitory effects. They may last for seconds, minutes, hours, or even days. Certain effects can be encountered only at particular seasons of the year; others know no season. To be seen, they may require observation sharpened by special interest, an intensity of visual awareness seldom achieved in Western cultures.

Five groups of influences give ephemeral effects to the landscape — or for brief periods cause the ephemeral landscape to exist. They are (1) atmospheric and weather conditions, (2) projected and reflected images, (3) displacements, (4) signs, and (5) animal occupancy. We have already touched upon certain of these influences, but they bear repetition because they bring a special quality to the appreciation of landscape.

Atmospheric and weather conditions (fig. 46) are most extensive. They can be assigned to four sub-divisions: cloud and fog formations, precipitation, vagaries of light, and wind-motion effects. Many of these influences will be self-evident, and only a few of the vast number of possibilities are noted for their visual contrasts and enrichment:

> Cumulus clouds as billowing, complimentary forms above the horizontal plane of a panoramic landscape.
>
> Fog spilling through a gap, defining the bottom of an enclosed landscape.
>
> Hoarfrost or backlit raindrops outlining tree branches in the foreground distance.

Figure 46 — Ephemeral landscape, weather condition, low cloud cover. (Childs Meadow, Lassen National Forest and National Park, California.)

Sunset coloration on a feature landscape; rainbow arched over space.

Scintillation of light bouncing off wind-driven aspen leaves.

Formation of sand ripples in shallow water; their evolution by wind over sand.

Cloud shadows sweeping across a broad and placid middleground landscape.

Projected and reflected images (fig. 47) are secondary images of plants, terrain features, or clouds. They may be seen as shadows projected by light upon solids or as reflections upon water. The light source may be either the sun or moon. Or, light itself may be reflected from a water body or other surface without involving the image of some solid element.

Shadows or reflections of an object are seldom seen complete, and hence they tend to be accepted as normal visual reinforcements of the object itself. To actually look at shadow pattern requires specific intention — and the advantages of a simple plane for projection which will minimize distortion of the image. In the Ginka kuji, a medieval Japanese garden, a smooth sanded surface was prepared for receiving sun-or-moon-cast shadows of trees which could be seen from the adjacent veranda. Reflections on pond surfaces were similarly and consciously enjoyed.

Reflections should normally be more conspicuous than shadows. They have the color attributes of the original though somewhat darker. On still water, the reflected shape is a mirror image of the real form. If the observer position and the reflecting surface are suitable, the secondary image can be complete and can enhance ease of recognition.

Figure 47 — Ephemeral landscape, reflected images. (Ten Lakes, Yosemite National Park, California.)

Light reflections simply as redirected light rays are conspicuous enough since they appear as highlights at edges or on surfaces. Like shadows, though, they probably are accepted as part of a normal expectation rather than as subjects of actual observation. Also, discomfort to the eyes may thwart the conscious effort to look at light reflections.

Displacement (fig. 48) has to do particularly with the parts of plants which have been detached from their place of growth and are found in a new context: leaves upon the ground or floating in water, fruit fallen to the earth, or flower petals shattered and dropped to ground or water. Wind-fallen trees, shed bark, and driftwood may also be included as displacements. Except for driftwood, such dislodged pieces tend to be ignored visually once they leave their expected place. But there is a difference in visual impact depending upon whether the observer is driving or walking. For example, leaves and flowers in place are readily seen from the automobile; after dislodgement, they are still visually available but most of their value will be to the pedestrian.

Signs (fig. 49) refers to indications of former life or occupancy by animals or plants. Animal and bird tracks, beds and bird nests, spider webs and insect egg cases, bird feathers and snake skins — all attest to the fact that living creatures have been present or may be nearby. Dead tree snags and standing skeletons of last summer's annuals indicate life that was or will be again. The water dimples left by a rising fish are also signs that are easily seen though the maker may escape notice. Signs, like elements of the detail landscape, are pedestrian concerns for the most part. And similarly, they can enrich appreciation and awareness of the larger landscape.

Figure 48 — Ephemeral landscape, displacement, hawthorne fruit on the ground. (Berkeley, California.)

Figure 49 — Ephemeral landscape, signs, racoon tracks. (Dry Creek, Healdsburg, California.)

Animal occupancy is a transitory influence only in the sense that sightings are apt to be short-lived, or require special insight on the part of the observer. The animals are a permanent or seasonal segment of the total living landscape but invisible to many who pass by. Certainly the full complement of animal occupants will be unknown to most. Signs can suggest existence of animal habitats but they too are subtle symbols.

Even though the ephemeral landscape may be beyond susceptibility — or desirability — to control, it adds so much to appreciation of the environment that land managers and landscape architects should develop a special sensitivity to this compositional type and thus to recognition of the full complexity of the landscape.

Landscape Inventories

The previous sections described factors of scenic analysis and their representation in compositional types. But this analysis remains to be made feasible in the form of technique applicable to real forest situations. To aid landscape architects and land managers, two case studies are presented here. They provide documentation of analytical factors — distance zones, observer position, etc. — and compositional types for planning purposes. No one annotation method seems adequate to record a complete range of all the elements that make up the landscape. Therefore, several methods of documentation are shown.

One common basis employed is a visual corridor plotted on a topographic map. This procedure makes use of existing roads — or a single route — from which the visual limits are plotted. However, the approach is a matter of convenience. The same kind of plotted base showing the scenic corridor can be projected for a proposed road or trail.

A criticism of visual corridor plots is that they fall short because they do not include an evaluation of areas beyond the corridor. I can only recommend that the visual corridor should not be treated as a screen strip or a way to camouflage what may be allowed to happen beyond the corridor. Comprehensive policies for management of the landscape resource must embrace a regional sense of the problem. The visual corridor should be recognized as a sample of a larger regional landscape and not as a device to ignore the remainder or condone neglect beyond the viewed zone.

The two examples show different applications of inventory technique. The first (Shaver-Huntington Lake) develops from a conventional map base, through a series of abstractions and simplifications that may be useful for specialized purposes (figs. 50-55). The second (Pollock Pines-Meyers Grade) develops a record in terms of conventional description and photographic sampling (figs. 56-57). A variety of means were used to collect original field data — in particular, black and white and color photographs, and plotting in 7½ and 15 minute U. S. Geological Survey topographic maps — including use of abstract notation symbols, and landscape analysis check lists. Examples of both abstract notation symbols and a check list will be found in the appendix, but no special emphasis of these procedural steps is made in this report. I acknowledge a basic dependence upon the development of notation systems contained in the work of Donald Appleyard, Lawrence Halprin, Philip Lewis, Jr., Kevin Lynch, John Meyer, and Philip Thiel. Reference to the bibliography will provide sources of detail on their notational procedure.

SHAVER-HUNTINGTON LAKE SERIES

State Highway 168, Sierra National Forest, California.
Length: 15½ miles, travel time: 25-30 minutes.

The route begins and ends with lakes and their basins of contrasting scales. The middle point consists of two ridges or road summits, with a lodgepole pine forest and creek basin between well-defined forest types which are an accompanying sequence of the road and which have contrasting visual and spatial effects (see Figure 54).

Except at the two larger terminal basins and the lesser, midway lodgepole pine basin, the roadway is essentially an enclosed corridor in which foreground and middleground distances predominate. Because of this simple corridor continuity, the variations of the forest types become important in themselves and in the spatial differences they provide. Spatial difference is largely due to limitations of sight into the stands. Depth of penetration is greatest in the black oak-pine forest, owing to open stand, low brush, and granite exposure; second greatest in red fir because of clean boles with virtually no understory; third in mixed conifers at the 5,000-6,000 foot elevation, where seedlings and shade-tolerant species such as white fir tend to occupy much ground and air space; fourth, and most restrictive, is the lodgepole pine type in which new growth of seedlings along the roadside tends to be dense, and the stand is relatively impenetrable both physically and visually.

In the central part of the route, Tamarack Basin is apparent between Tamarack Ridge and the Huntington Maintenance Station summit, the center being marked by Tamarack Creek which is, visually, the only obvious stream on the whole route. Tamarack Creek is easily accessible and is the focal attraction of the basin. The small scale of the basin, with middleground views of 2 to 3 miles to the enclosing ridge, is maintained by the small scale of the lodgepole pine stands. Although the screening effect of the lodgepole stands is quite restrictive, minor changes of vertical alignment in the road in this area allow distinct ridge sightings and occasional views into stand openings. The side slopes of the basin are marked by red fir forest of large trees with distinct blue-green color, contrasting with the basin floor of lodgepole pine forest — small trees with yellow-green color.

A rather subtle scenic theme found throughout the route is in the exposure of the granitic base: the domes of Ely Mountain, of Bald Mountain and vicinity, the erratic boulders which make a number of close-in feature points, and the barren ridge surfaces at Kaiser Ridge and above Big Creek.

The main variation in visual experience due to east-west or west-east travel occurs toward the terminals and is related to downhill movement along side-hill tangents and outside curves. Thus the Huntington Lake basin and water surface sightings are most apparent with west to east travel, whereas the Shaver Lake basin and its water surface sightings are most apparent with east to west travel. Regardless of travel direction, Huntington Lake is virtually hidden as compared to Shaver Lake. Three factors account for the difference: basin form and size, distances from station point, and roadside tree screening. Turnouts or "interest points" are provided at points above both lakes. For all practical purposes, Huntington Lake can be seen only by stopping. Shaver Lake, however, may be readily seen in transit, particularly from the oak-pine forest area west of Tamarack Ridge, 6 to 9 minutes away from the lake. Travelers cannot fail to see that the two lakes are markedly different in scale. But more important, there is an understanding of Shaver which is absent in Huntington. In east-west travel, Shaver is seen *in toto*

from a distance of about 4 miles, with the observer in superior position, and 6 to 9 minutes later, close up. Huntington, for the moving observer, occurs as a surprise element and is seen only from near water's edge and level. Kaiser Ridge and the enclosed landscape of the Huntington Lake valley provide a major impression long before Huntington Lake surface can be seen.

Landscape inventories are documented in figures 50, 51, 52, 53, 54, and 55.

POLLOCK PINES-MEYERS GRADE SERIES

U. S. Highway 50, Eldorado National Forest, California
Length: 40 miles, travel time: 1 hour.

View Categories

The original plotting of this scenic corridor — between Bridal Veil Falls and Meyers Summit — was done in July 1965 with William Fischer, recreation planner for the California Region of the Forest Service, and Robert Henley of Eldorado National Forest. The corridor was delineated as a series of view categories to which timber management prescriptions were keyed (fig. 56). The categories and prescriptions were as follows:

LANDSCAPE MANAGEMENT – TRAVEL INFLUENCE ZONE
U. S. HIGHWAY 50 – ELDORADO NATIONAL FOREST

View Categories and Management Prescriptions

(Numbers refer to view categories in figure 56.)

View Category

2. Foreground — Direct: Observer inferior, moderate to steep, forested, undisturbed.

Management Direction	Timber —	Light selection, retain hardwoods. Avoid vertical skidways.
	Roads —	Retain screen lower side. Low standard roads only.
	Uses —	Screen uses, key power lines out of these areas.

3. Foreground and Middleground: Observer inferior, moderate to steep, disturbed, fire scars and plantations.

Management Direction	Timber —	Light selection in timbered areas. Fall all dead trees.
	Roads —	Promote revegetation and healing of road scars. No new roads across open areas until screening can be established.
	Uses —	Screen uses, power lines below ridge tops and no closer than 1 mile from highway.

4. Foreground — Direct and peripheral: Steep to precipitous, forested.

Management Direction		Critical view area, no disturbance permitted by road construction or other uses. No uses permitted. Remove from timber use category.

5. Foreground — peripheral: Steep, undisturbed, forested.

Management Direction	Timber —	Normal selection; retain hardwoods. Screen skidways.
	Roads —	Screen from lower side.
	Uses —	Screen uses.

6. Middleground — Direct and peripheral: Moderate to steep, undisturbed, forested, occasional brush fields.

Management Direction	Timber —	Normal selection to shelterwood on moderate slopes; retain hardwoods. Avoid vertical skidways.
	Roads —	Screen on lower side. Avoid large cuts and fills. Allow no roads across brushfields.
	Uses —	Screen uses. Keep power lines below ridge stops, minimum clearing no closer than 1 mile from highway.

7. Special Feature — Foreground: Rock spire, steep, undisturbed, forested.

Management Direction	Manage as scenic area, allow no visible disturbance to ground or vegetation. Permit trails and rock climbing.

8. Foreground — Direct and peripheral: Observer superior, steep, critical situation.

Management Direction	Same as 4. Any ground or vegetation disturbance will detract.

9. Middleground — Enclosed landscape: View with features.

Management	Allow no visible disturbance.	
Direction	Timber —	Sanitation only if screened out at cutting location. No visible skidways
	Roads —	No visible roads, no disturbance of brushfields.
	Uses —	No power lines, no unscreened uses.

Sequence Zones

The Highway 50 route was also plotted separately between Pollock Pines and Meyers Grade (fig. 57). Nine different sequence zones or segments of the corridor were designated as areas of individual character within the landscape as travel progresses from west to east:

Zone 1. — Introduction and orientation to the Sierra Nevada crest seen 22 miles away from Union Hill. Spatially restricted to the south with open aspects to north and east over the American River valley, this panoramic view to the ridge is maintained intermittently for 3 miles, or about 4-5 minutes.

Zone 2. — Downward descent toward the American River. The road continues along the shaded face; views outward to north and east are of middle distance restriction. A marked difference in forest types begins to register: a dense mixed-conifer stand on the shaded north exposure; an open oak-conifer mixed stand on the sunny face. This zone runs for slightly more than 3 miles, or about 5 minutes.

Zone 3. River contact made near the Riverton Bridge. A good downward aspect of the river is seen from an easy horizontal curve. There is some marring of the riparian area by invasion of the highway through stream bed disruption and fill overcast. This zone runs for a mile, or about 1½ minutes.

Zone 4. — Road shifts from shady to sunny side of the river at the Riverton Bridge. River contact is intimate, and uphill travel has the advantage of being on the streamside lane. There is a general continuity of riparian vegetation — alders and maple. Conifers predominate to the shady side; oaks predominate to the sunny side. Variations of the stream course are closely followed by road alignment. Summer homes and a few restaurants are along the stream but do not seriously break its continuity. This zone runs for 10 miles, or about 15 minutes.

Zone 5. Sugar Loaf, a rock spire feature, marks departure from stream course contact. Sugar Loaf is visible from about 1/3 mile on either side — if the light is advantageous. This feature is at Kyburz, where there are some scattered buildings and crude handling of the intersection leading to the highway maintenance station. Eagle Rock, a rock cliff feature, is immediately above Kyburz. The cliff marks the beginning of a consistent timber corridor, which runs for 7½ miles, or about 11 minutes.

Zone 6. — Visual contact with the granitic character of the Sierra crest begins as the turn is made above Pyramid Peak Guard Station. This view is an enclosed landscape at Strawberry with a series of inclusions: scattered buildings, Lover's Leap cliff feature, pine corridor with exfoliating dome adjacent, creek crossing at Twin Bridges, and grade ascent on Ralston Peak face. Horse Tail Falls may be seen (with effort) from near grade top, and the enclosed landscape is reiterated from the upper turn and lip of the space. Granitic exposure is marked, reinforced by brushfields and scattered pines. This view is confirmation of the ridge panorama seen from Union Hill — Zone 1. It is clearly a climax at this stage of the route. The zone runs for 4 miles, or about 6 minutes.

Zone 7. — A short transition area at the top of Ralston ridge is marked by an abandoned ski run and subtle awareness of Camp Sacramento. The old ski run suggests a need for better recognition and handling of such facilities for off-season appearance. This zone runs for about a mile, or 1½ minutes.

Zone 8. — An ecological change is manifested in this zone as a fir-lodgepole pine corridor. There is close contact with the forest stand and some sense of canopy closure. One blatant sign intrusion is encountered. The zone runs for 4½ miles, or 7 minutes.

Zone 9. — Emergence from the fir-pine channel brings travelers to the Meyers Grade climax panorama of the Tahoe basin. Outward views north are long — over Lake Tahoe, middle distance views to east and south into the local space of Lake Valley and its defining ridges. Some signs of the South Shore clutter are evident but not yet acute because of the distance. The descent, and northerly oriented attitude into the basin, runs 5 to 6 miles, or 8 to 10 minutes.

FIGURE 50

LANDSCAPE INVENTORY VISUAL CORRIDOR

SIERRA NATIONAL FOREST SEGMENT, HWY. 168
BETWEEN SHAVER LAKE & HUNTINGTON LAKE, CALIF.

NORTH

0 1 2 3 MILES

SCALE

LEGEND:

- (1) MILEAGE MARKS
- FOREGROUND BOUNDARY (¼ MI. FROM ROAD)
- MIDDLEGROUND BOUNDARY (3 MI. FROM ROAD)
- VISUAL CORRIDOR BOUNDARY

AREAS

FOREGROUND (WITHIN ¼ MILE OF ROAD)
5150 AC.

MIDDLEGROUND (BETWEEN ¼ & 3 MILES FROM ROAD)
22540 AC.

BACKGROUND (OVER 3 MILES FROM ROAD)
6520 AC.

WATER AREAS 3320 AC.
HUNTINGTON LAKE 1270 AC.
SHAVER LAKE 2050 AC.

TOTAL AREA, 37,530 ACRES

BASE MAP SOURCE: USGS, 7½ MINUTE SERIES

FIGURE 51

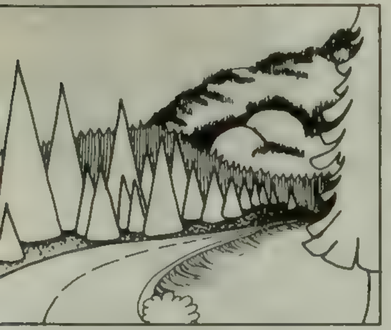
LANDSCAPE INVENTORY

1ST STAGE ABSTRACTION
SIERRA NATIONAL FOREST SEGMENT, HWY. 168
BETWEEN SHAVER LAKE & HUNTINGTON LAKE, CALIF.

LANDSCAPE INVENTORY
1ST STAGE ABSTRACTION

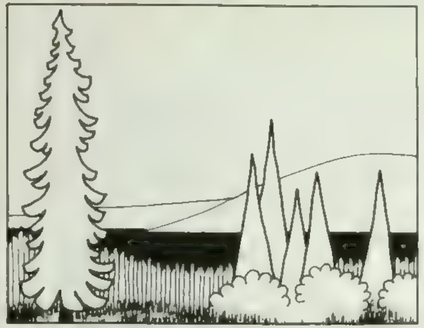
URE 52 **LANDSCAPE INVENTORY, FIRST STAGE ABSTRACTION, NO. 2,** SIERRA NATIONAL FOREST SEGMENT MILEAGES REFER TO DISTANCE ALONG ROAD IN FIGURE 51

MG = MIDDLEGROUND, BG = BACKGROUND

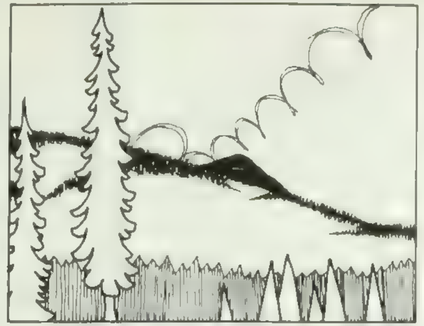


MI. FEATURE LANDSCAPE
ELY MT. DOMES – MG.

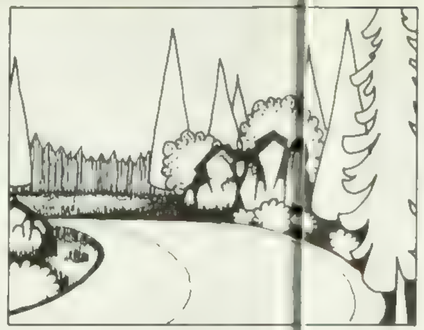
0.5 MI. FOCAL LANDSCAPE
MIXED CONIFER CORRIDOR – FG.



2.0 MI. FEATURE LANDS. (ENCLOSED)
SHAVER LAKE – MG.



3.2 MI. FEATURE LANDSCAPE
BALD MT. – GRANITE EXPOSURE – BG.



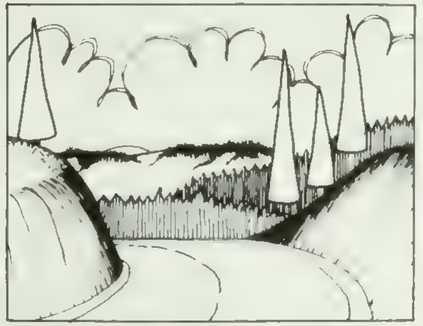
3.4 MI. FEATURE LANDSCAPE
ERRATIC BOULDERS – F

3.8 MI. ENCLOSED LANDSCAPE
MIXED CONIFERS – MG.

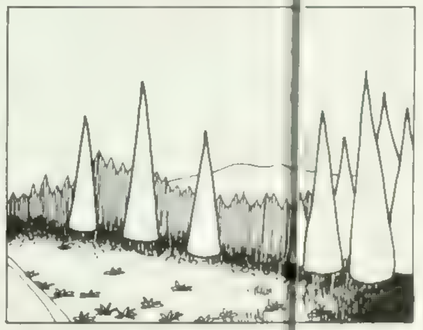
MI. PANORAMA, (FEATURE)
SHAVER LAKE – MG, PINE RIDGE – BG.

4.6 MI. ENCLOSED LANDSCAPE
BLACK OAKS – FG.

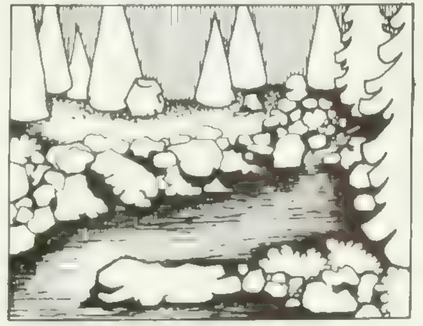
4.8 MI. FEATURE LANDSCAPE
GRANITE DOME – MG



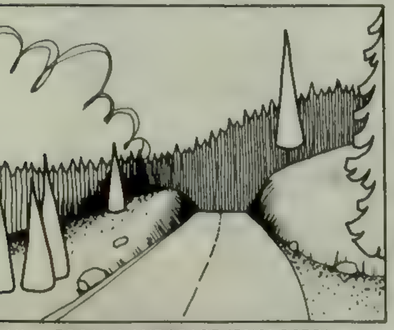
6.8 MI. ENCLOSED LANDSCAPE
TAMARACK BASIN – MG, KAISER RIDGE – BG.



7.0 MI. ENCLOSED LANDSCAPE
LODGE POLE PINE, TAMARACK BASIN – MG.

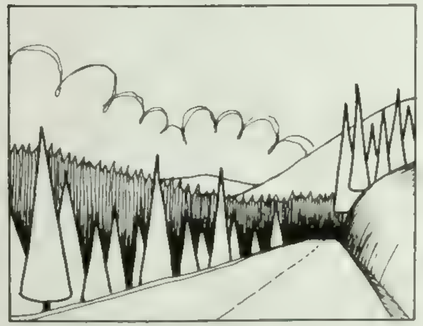


8.8 MI FEATURE LANDSCAPE
TAMARACK CREEK – FG.

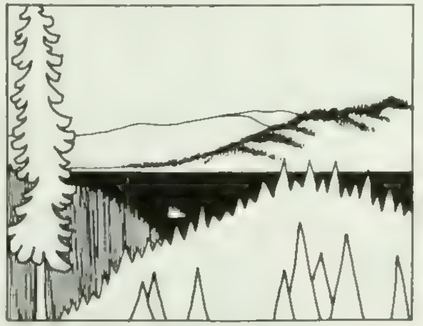


MI. FOCAL LANDSCAPE (ENCLOSED)
RED FIR – MG.

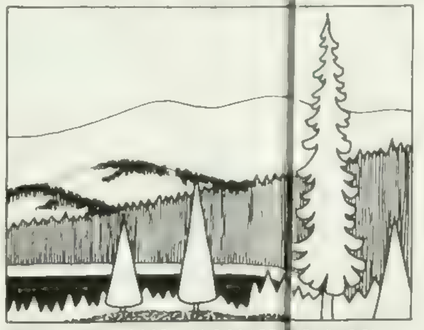
10.1 MI. FEATURE LANDSCAPE
HUNTINGTON LAKE – MG,
KAISER RIDGE – BG



12.6 MI. FOCAL LANDSCAPE
RED FIR CORRIDOR – MG.



12.9 MI. ENCL. LANDS. (FEATURE)
HUNTINGTON LAKE – MG,
KAISER RIDGE – BG



13.5 MI. ENCLOSED LANDSCAPE (FEATURE)
HUNTINGTON LAKE – MG

15.6 MI. ENCLOSED LANDSCAPE
LOW RIDGE – MG.

ORIENTATION OF SUN TO ROAD – (MAY 22 & JULY 22)

ORIENTATION CONDITION
RELATIVE TO OBSERVER & LANDSCAPE LIGHTING:
ADVANTAGE: SUN BEHIND OBSERVER, SUN SCREENED, LANDSCAPE SIDE OR FRONT LIT
DISADVANTAGE: SUN IN FRONT OF OBSERVER, OPEN SUN, LANDSCAPE BACK LIT

EASTBOUND
MORNING (10 A.M.)
DISADVANTAGE | ADVANTAGE
AFTERNOON (2 P.M.)
ADVANTAGE | ADVANTAGE

WESTBOUND
MORNING (10 A.M.)
ADVANTAGE | ADVANTAGE
AFTERNOON (2 P.M.)
DISADVANTAGE | DISADVANTAGE

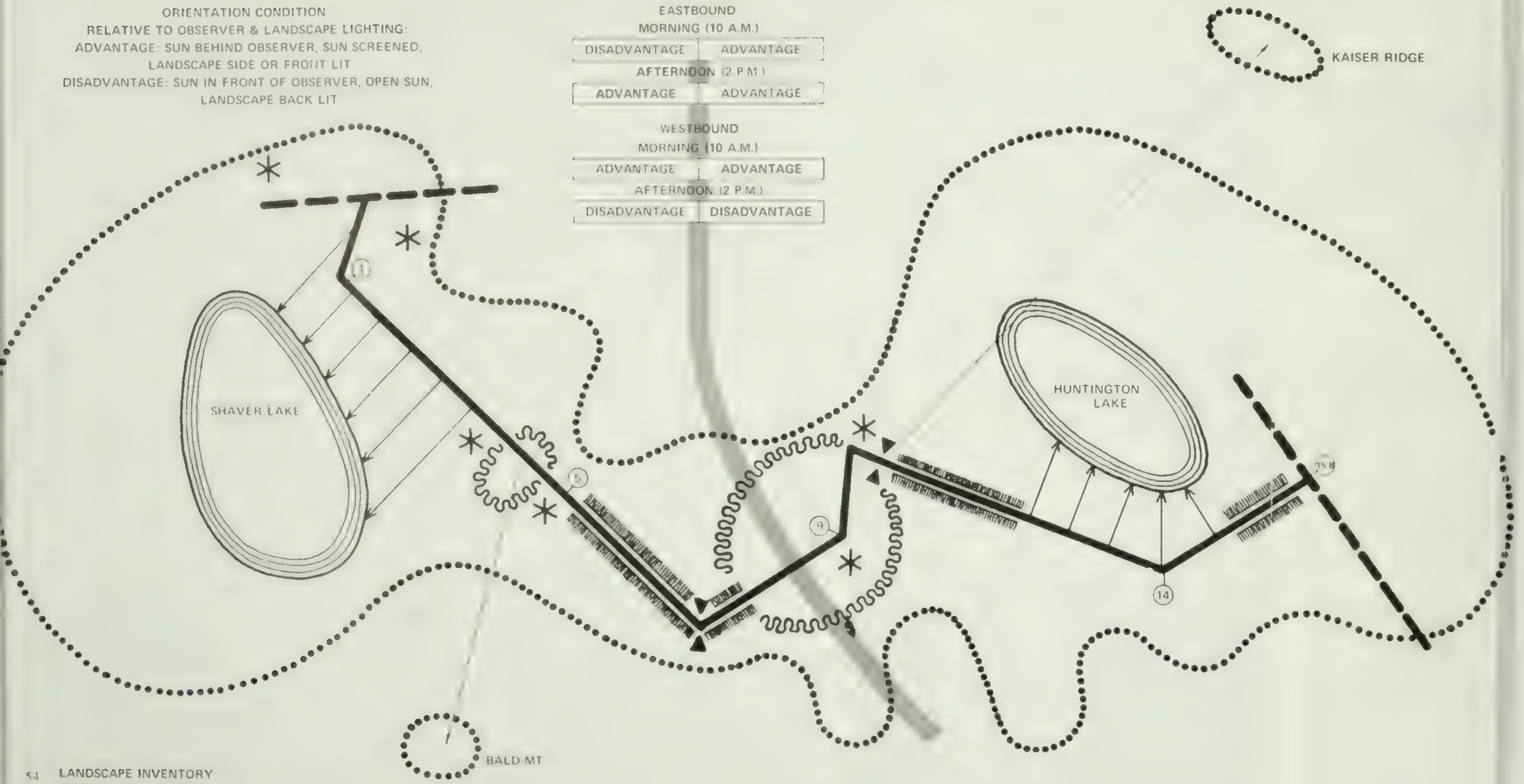


FIGURE 53

LANDSCAPE INVENTORY

2ND STAGE ABSTRACTION ROUTE & SUN ORIENTATION
SIERRA NATIONAL FOREST SEGMENT, HWY 168
BETWEEN SHAVER LAKE & HUNTINGTON LAKE, CALIF.

NORTH

0 1 2 3 MILES
SCALE

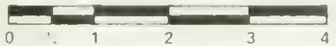
LEGEND

- MILEAGE MARKS
- ROAD SUMMIT
- LINE OF SIGHT, SIGHTING
- FEATURE (DOMINATED) LANDSCAPE
- ENCLOSED LANDSCAPE (SPACE)
- FOCAL LANDSCAPE; CONIFER CORRIDOR
- BOUNDARY OF VISUAL CORRIDOR

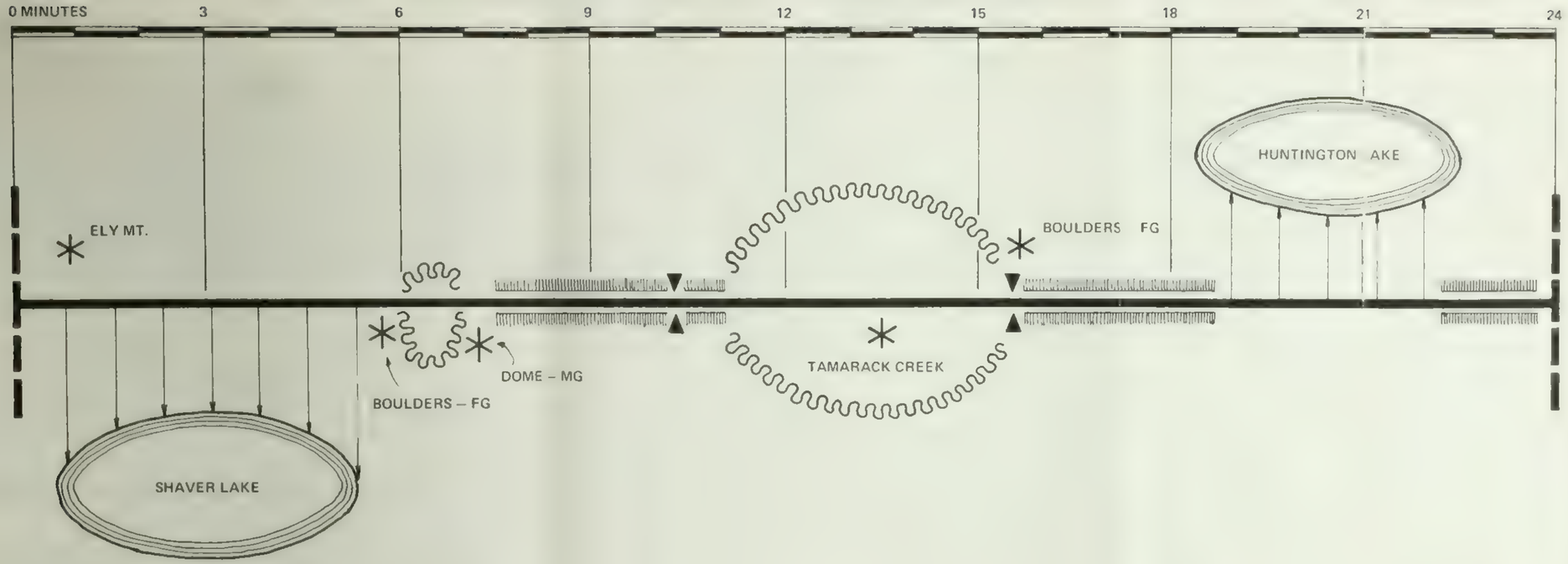
FIGURE 54

LANDSCAPE INVENTORY

3RD STAGE ABSTRACTION TIME & PROFILE LAYOUT
SIERRA NATIONAL FOREST SEGMENT, HWY 168
BETWEEN SHAVER LAKE & HUNTINGTON LAKE, CALIF

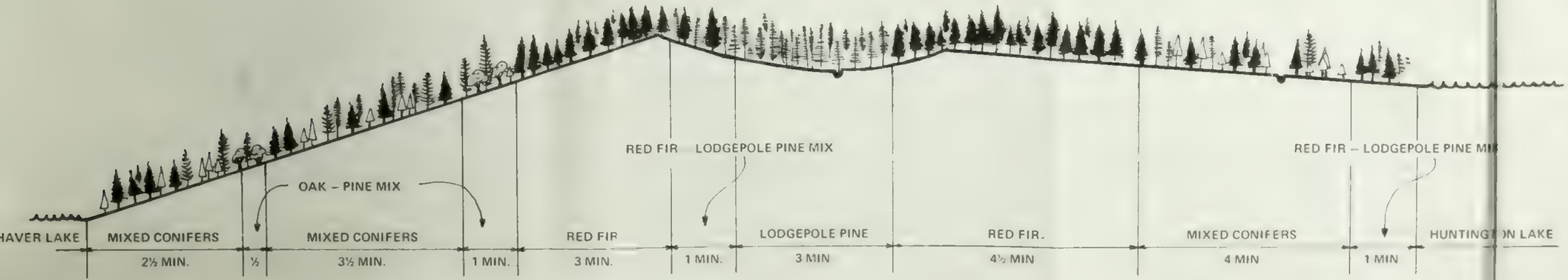


SCALE IN MINUTES; BASED ON
SPEED OF 40 MILES PER HOUR



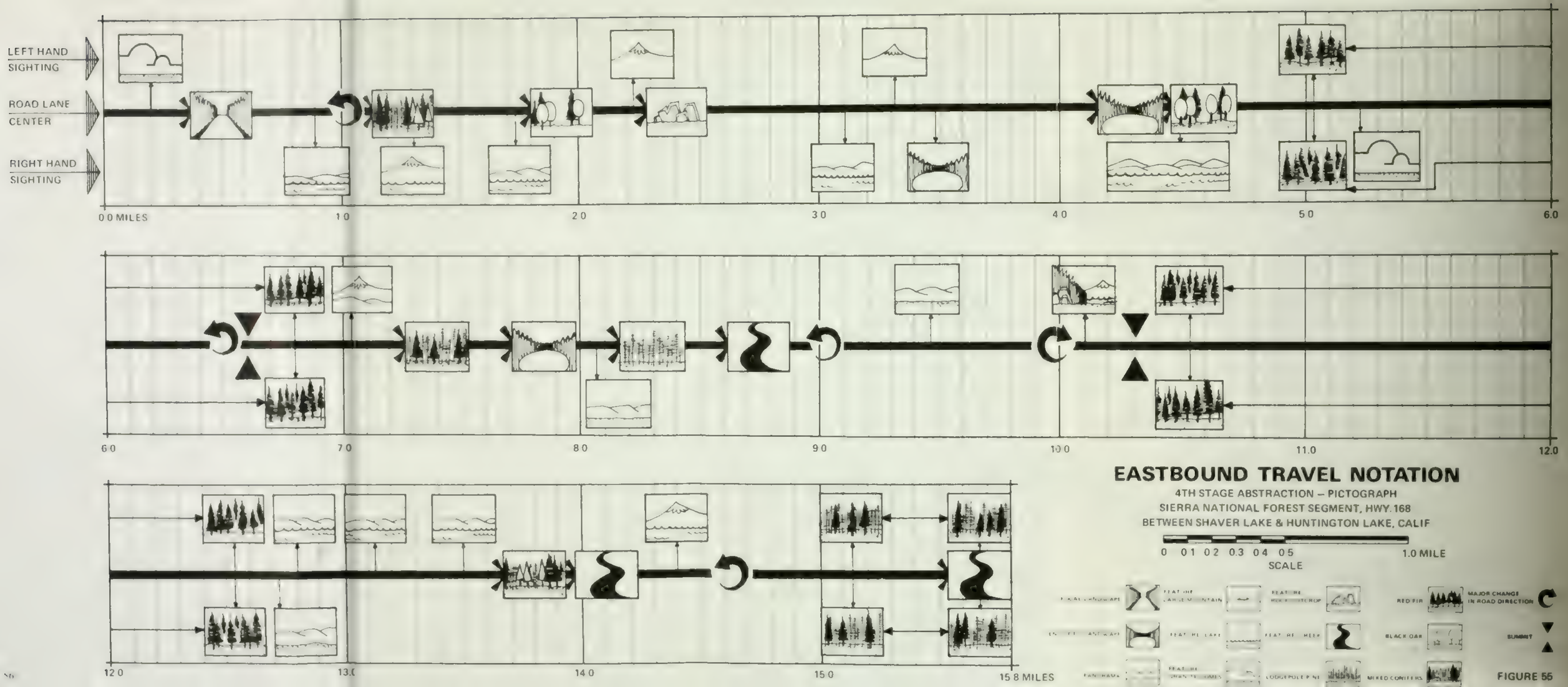
'LAN LEGEND:

- LINE OF SIGHT
- ROAD SUMMIT
- FOCAL LANDSCAPE; CONIFER CORRIDOR
- FEATURE (DOMINATED) LANDSCAPE
- ENCLOSED LANDSCAPE (SPACE)



PROFILE OF HWY 168

SHOWING TREE TYPES



EASTBOUND TRAVEL NOTATION

4TH STAGE ABSTRACTION – PICTOGRAPH
SIERRA NATIONAL FOREST SEGMENT, HWY. 168
BETWEEN SHAVER LAKE & HUNTINGTON LAKE, CALIF

0 01 02 03 04 05 1.0 MILE
SCALE

RED FIR — MAJOR CHANGE IN ROAD DIRECTION
BLACK OAK — SUMMIT
MIXED CONIFERS

FIGURE 55

LANDSCAPE
INVENTORY

FIGURE 57

LANDSCAPE INVENTORY: SEQUENCE ZONES

U.S. HIGHWAY 50 - EL DORADO NAT. FOREST - POLLOCK PINES - MEYERS GRADE SEGMENT

ZONE 1

ZONE 2

ZONE 3

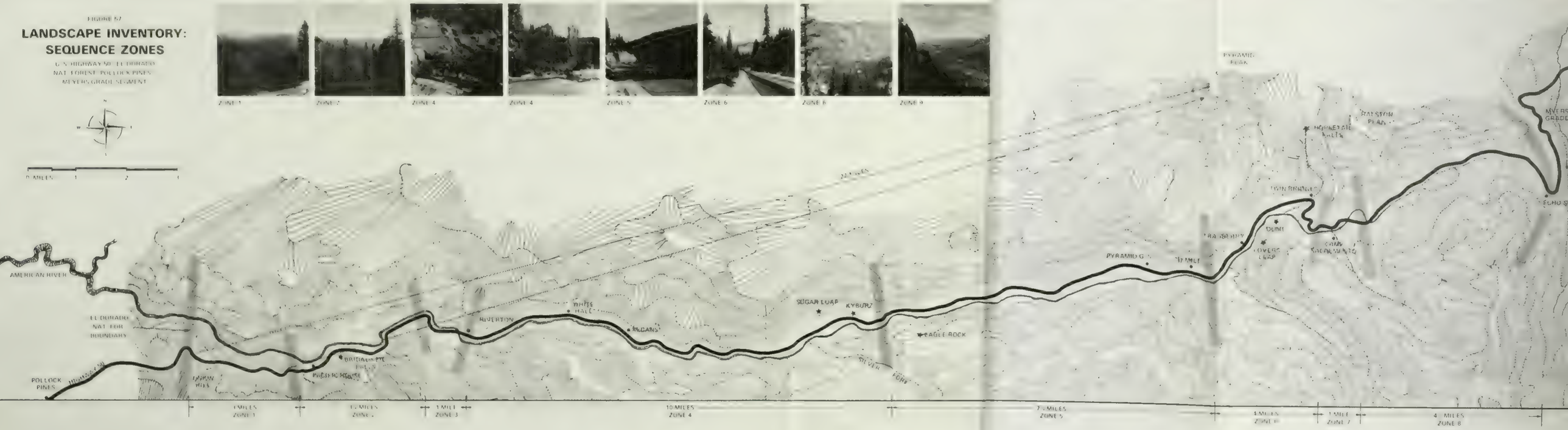
ZONE 4

ZONE 5

ZONE 6

ZONE 8

ZONE 9



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Appendix

FIELD RECORDING: LANDSCAPE OR SCENIC NOTATION, SYMBOLS AND ABBREVIATIONS: FOR USE WITH TOPOGRAPHIC MAP

SCENE

Panorama

Focal Landscape

Feature or Feature-dominated landscape

Enclosed (Spatial) landscape

Park-land (canopied)

Screen

Channel

DISTANCE, VIEW TYPE

Distant-Background (Exceeding 3 mi.)

Intermed.-Middleground (¼ to 3 mi.)

Close-in Foreground (0 to ¼ mi.)

OBSERVER POSITION AND VIEW POINT

Observer superior

Observer normal

Observer inferior

Outlook or Overlook

Channeled Vista

Ridge Tangent

Sidehill Tangent

In Curvature

Side Enclosure

LANDSCAPE ANALYSIS CHECK LIST

LOCATION _____
DATE _____
HOUR _____

OBSERVER POSITION	S										
	N										
	I										
OBSERVER	*F. G.										
	*M. G.										
	*B. G.										
SCENE COMPOSITION	PAN.										
	ENCL.										
	FOCAL										
	*FEATURE										
	CANOPY										
	OTHER										
*PLANT ASSOC.											
LIGHT	B										
	F										
	S										
	INTENSE										
	DK.										
	DIFF.										
OTHER											

START

MILES 0 1 2 3 4 5 6 7 8 9

NAME, DESCRIPT.

*DEFINE

_____
Observer

SEQUENTIAL CONTRAST CHECK LIST

1. FORM — as manifested by domination due to
   - A. Isolation
   - B. Size and scale
   - C. Contour distinction, silhouette
   - D. Surface variation — shapes, patterns, textures

2. SPATIAL DEFINITION
   - A. Degree of definition; floor-to-wall proportions
   - B. Nature of enclosure and floor; floor configuration
   - C. Size and scale

3. LIGHT
   - A. Color
     1. Hue and value
     2. Aerial perspective (distance)
   - B. Direction
     1. Back lighting
     2. Side lighting
     3. Front lighting
     4. Relationships to land form and surface
        - a. Skyline silhouette
        - b. Surface, gradient, orientation
   - C. Intensity

4. DISTANCE
   - A. Foreground
     1. Detail, restriction
     2. Presence
     3. Scale
   - B. Middleground; linkage, perspective
   - C. Background; simplification, foil
   - D. Aerial perspective — light

5. OBSERVER POSITION
   - A. Observer inferior
     1. Restriction
     2. See foreground
   - B. Observer normal
     1. Comprehensive combination
     2. See middleground
   - C. Observer superior
     1. Orientation
     2. See background

6. COMPOSITIONAL TYPES
   - A. Larger scale
     1. Panoramic landscape
     2. Feature landscape
     3. Enclosed landscape
     4. Focal landscape
   - B. Smaller scale
     1. Canopied landscape
     2. Detail landscape — minutiae
   - C. Transitory designation — ephemeral landscape

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

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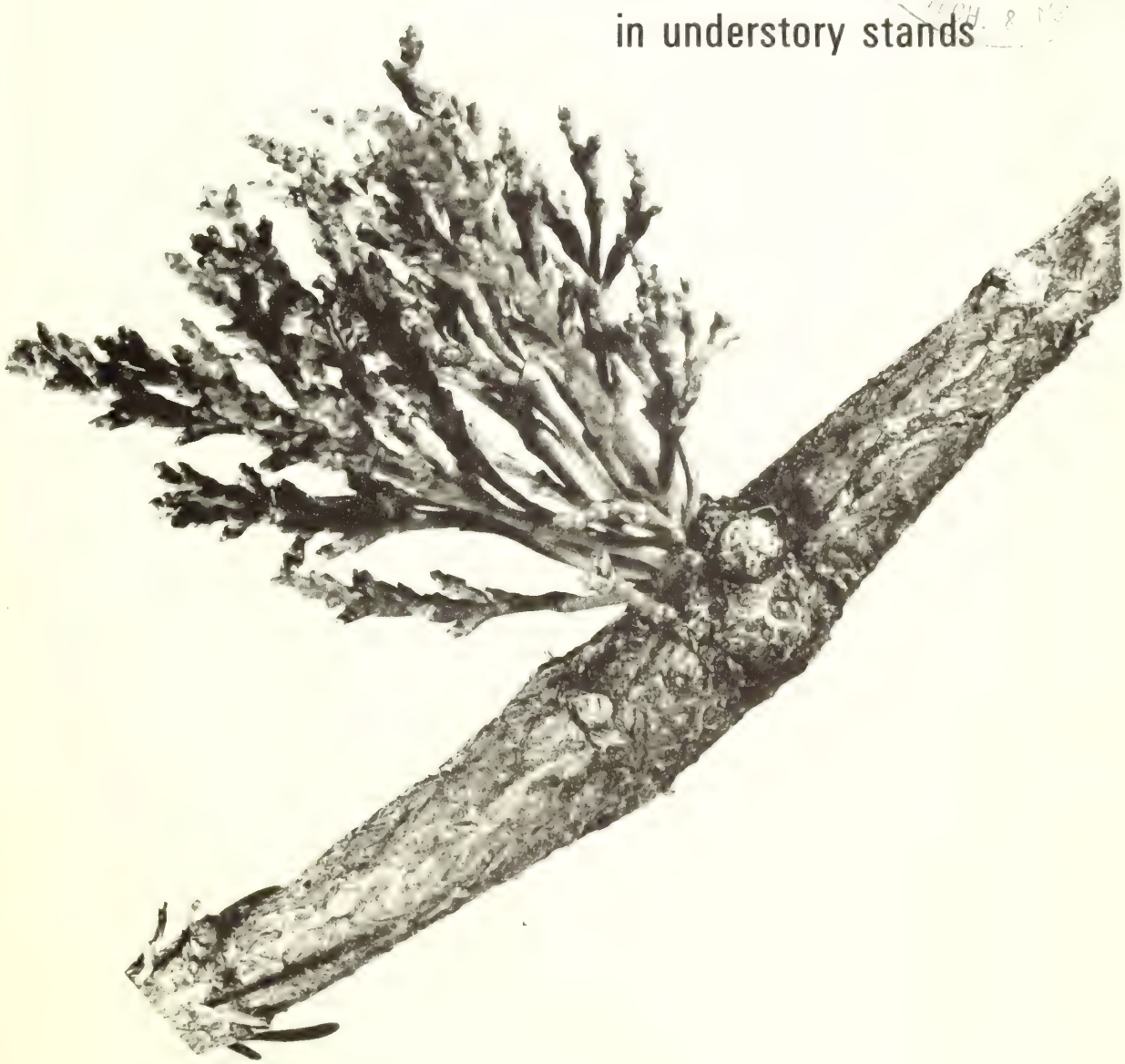
DWARF MISTLETOE ON RED FIR . . . .

infection and control in understory stands



U.S.D.A. FOREST SERVICE RESEARCH PAPER PSW-50 1969

Dwarf Mistletoe On Red Fir . . . infection and control in understory stands

ROBERT F. SCHARPF

Contents

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The Author

ROBERT F. SCHARPF, a plant pathologist, is studying problems in forest diseases and their control. Native of St. Louis, Mo., he earned a forestry degree (1954) at the University of Missouri. He also holds a master's degree in forestry (1957) and a doctorate in plant pathology (1963) from the University of California, Berkeley. He joined the Forest Service in 1960, and has been with the Station's Berkeley research staff since then.

Red fir (*Abies magnifica* A. Murr.) composes about 10 percent of the total net volume of live sawtimber in California's commercial forest land (Calif. Forest & Range Exp. Sta. 1954). For the most part, this species grows as pure stands at high elevation. Its range extends from the southern Cascade Range of Oregon through California's northern Coast Range and Sierra Nevada. Forest managers did not begin logging red fir in appreciable volume until the late 1940's because of its relative inaccessibility.

A producer of wood of good quality, red fir is destined to grow in economic value (Hallin 1957). The species is also valuable in many forested areas used for recreation purposes. It helps regulate the melt of the snowpack in the high mountains of California (Anderson 1963). And when properly managed and harvested, it is sought after as a Christmas tree crop.

Because of the increasing value of red fir stands, forest managers are concerned about any hazards to the species. The continued demand for timber products, recreation, water, and other benefits derived from multiple-use forests requires an increased effort in managing red fir stands.

Among the most serious parasites of conifers in western North America is the dwarf mistletoe (genus *Arceuthobium*). Offord (1961) estimated that about 200 million board feet are lost annually from the effects of this parasitic plant in California's forests. Throughout the State, dwarf mistletoe is wide-spread and severe in red fir stands (California Forest Pest Control Action Council 1968). In a survey, about 45 percent of random plots examined held infected trees. And on the average, about 35 percent of the trees on these plots were infected. Therefore, losses in red fir alone amount to a large percentage of the total loss of timber from the effects of dwarf mistletoe.

The dwarf mistletoe that attacks red fir is *Arceuthobium campylopodum* Engelm. *f. abietinum* (Engelm.) Gill. It is identical morphologically to the species that attacks and infects white fir (*A. concolor* [Gord. and Glend.] Lindl.) and resembles dwarf mistletoes on other conifer species. But it is host specific—it infects only red fir (Parmeter and Scharpf 1963).

This paper reports a study of dwarf mistletoe on understory red fir growing in association with heavily infected overstory trees. It relates height and age of trees to both frequency and intensity of infection on study plots set up on four National Forests in California. And it suggests how the spread of and damage from this parasite in residual or newly established red fir stands might be reduced by applying silvicultural control.

The Parasite

Dwarf mistletoes spread by means of an explosive fruit mechanism. They cast their seeds for a maximum vertical distance of 15 feet and a horizontal distance of up to about 40 feet (Hawksworth 1959). Aided by wind, however, seeds discharged from plants in the tops of old-growth firs may spread to surrounding smaller trees for a distance of 100 feet—and probably sometimes even farther. The target area a tree presents has been recognized as a factor that influences infection of conifers by dwarf mistletoes (Childs 1963; Hawksworth 1958; Scharpf 1968; Wicker and Shaw 1967). And how long a tree is exposed to infection is also considered critical to infection (Childs 1963; Wicker and Shaw 1967). Either or both factors may be responsible for infection of red fir by dwarf mistletoe.

In general, the parasite spreads through a stand at a relatively slow rate. Hawksworth (1961) reported that dwarf mistletoe in young ponderosa pine stands in the Southwest spreads laterally about 1 to 2 feet a year. Thus, once dwarf mistletoe has been eliminated from an area reinvasion takes place very slowly. In spite of their slow rate of spread, dwarf mistletoes are a serious parasite of conifers in the West.

Figure 1.—*Bole swellings from dwarf mistletoe on red fir reduce timber quality and often make a tree nonmerchantable.*

Figure 2.—*Old dwarf mistletoe bole swellings on red fir may become insect riddled and decayed. Trees in this condition often break off as a result of the decay.*

This parasite damages firs in several ways. Badly infected trees, particularly suppressed understory trees, are deformed, killed, or weakened to the point that they succumb to insect attack. The larger heavily infected trees, although not often killed, have markedly reduced growth rates. Infections cause bole swellings on the main stem *(fig. 1)*. These bole swellings provide an opening for decay fungi and often make the tree unsuitable for harvest. Also trees with decayed bole swellings often break off at the swelling, endangering visitors and property on campgrounds and other recreational sites *(fig. 2)*.

General information is available on symptoms, damage, distribution, and control of dwarf mistletoe in mature red fir (Scharpf 1964). Also some aspects of the biology and pathology of red fir dwarf mistletoe have been investigated (Scharpf and Parmeter 1967). But information about infection and buildup of dwarf mistletoe in young stands and understory trees has not been available.

The Host

In general, natural red fir stands have certain silvical characteristics (Hallin 1957) that are favorable for spread and buildup of dwarf mistletoes. These characteristics may, in part, explain the abundance and severity of dwarf mistletoe in red fir in California:

- Within its normal range red fir grows as pure stands, or, if in mixed stands, often is the predominant species. Therefore, nonsusceptible trees do not limit the spread and buildup of the parasite.
- Red fir forms fairly dense stands, thereby allowing the parasite to spread easily from one crown to another.
- Red fir is intermediate in tolerance and will survive under partially shaded conditions. Understory trees surrounded by infected overstory are readily exposed to infection by dwarf mistletoe.
- Red fir understory trees grow slowly in height until they reach 12 to 15 feet tall; therefore, trees may become badly infected by dwarf mistletoe before they can reach a stage of optimum growth.

The most common method of harvesting red fir has been to clearcut fairly large blocks. But if no residual advance growth is present, the blocks may not be able to regenerate naturally. Whether the use of this cutting technique in large areas is esthetically disirable has—along with the problem of regeneration—led to studies of other systems of managing red fir. Research underway at the Pacific Southwest Forest and Range Station has suggested that other methods of harvesting firs, such as clearcutting in strips, or using seed tree and shelterwood methods, may improve natural regeneration and be more esthetically desirable.

Methods

To study red fir stands infected by dwarf mistletoe, I set up plots on four National Forests: the Stanislaus and Eldorado National Forests in the central Sierra Nevada, Plumas National Forest in the northern Sierra Nevada, and Lassen National Forest in the southern Cascades. These forests had infected stands that are representative of others in the State. Square 1/10-acre plots were established in pure red fir stands *(table 1)*. Information on density of stocking was obtained from a 1/100-acre subplot taken from the center of each of the 38 plots.

Three criteria were used to select the plots:

1. Heavily infected overstory had to be present on the plot. Dwarf mistletoe throughout the crown, broomed branches, and bole swellings on overstory trees were considered indicative of heavy infection.
2. Adequate understory trees up to 12 feet tall had to be present to obtain the desired number of sample trees in each height class.
3. Because the distance of spread of dwarf mistletoe from infected overstory to understory trees is limited, all understory trees on the plots had to be within 100 feet of at least one heavily infected overstory tree.

Trees to be sampled on each plot were randomly selected. For each tree desired, two coordinates were drawn from a table of random numbers and the points defined by these numbers located on a map of the plot. The 20 points were then located on the ground. The tree in the desired height class nearest a point was chosen as a sample tree. Five trees were chosen in each of the four height classes (0–3 ft., 4–6 ft., 7–9 ft., 10–12 ft.). Thus, with only a few exceptions, 20 trees from each plot were obtained.

The following data were collected in the field for each sample tree: tree height, number of infections per infected tree, and type of infection (bole or branch). Tree age was determined in the laboratory by counting the number of annual rings in a cross-sectional disc cut from the bole of the tree at ground level.

Results

The percentage of trees infected and number of infections per infected tree were directly related to tree height *(figs. 3, 4)*. Only 7 percent of the understory trees in the 0- to 3-foot height class were infected. On infected trees, a mean of only slightly more than one infection per tree (1.4) was found. Percentage of trees infected increased markedly above the 0- to 3-foot height class, and number of

Table 1.--*Plots set up to study dwarf mistletoe infection, by National Forest*

National Forest	Elevation	Location	Plots	Trees	Average understory trees/acre
	Feet		*number*		
Stanislaus	7,000	Near Pinecrest 30 mi. E. of Sonora	10	196	1,950
Eldorado	7,000	Near Lower Bear Reservoir	8	156	1,300
Plumas	5,700	5 miles west of Bucks Lake on Oroville-Quincy Road	10	195	3,470
Lassen	6,000	Swain Mountain Exp. Forest	10	193	2,570

infections per tree also increased significantly on trees above the 4- to 6-foot class. For the tallest trees examined (10- to 12-foot class), nearly 4 of 5 were infected, with a mean of about 11 infections per tree.

Age of understory trees appeared to have little effect on percentage of trees infected *(fig. 5)*. Only in one age class (0-20 years) were significantly fewer trees infected than in the other classes. As tree-age classes increased from 21 to 100 years, the increase in percentage infection was only about 20 percent. Too few trees more than 100 years were sampled to obtain any statistically significant results for this age class.

Trees in the 0- to 20-year age class had the fewest number of infections per infected tree *(fig. 6)*. Number of infections per infected tree appeared to increase somewhat for trees up to 60 years old, but afterwards dropped off slightly and then remained constant. Again, I did not obtain enough data on trees more than 100 years old to draw any significant conclusions about this age class.

Bole infections constitute the most serious type of infection on firs, even though only 6 percent of all infections recorded were bole infections. Bole infections deform small trees, cause pronounced swellings on larger trees, and eventually provide an opening for decay fungi, which makes boles par-

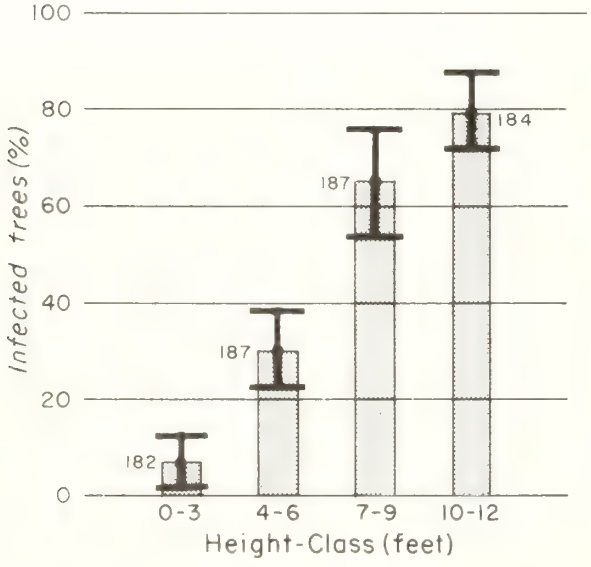

Figure 3.—*Percentage of red fir infected in each height-class, with 95 percent confidence intervals. The confidence intervals were interpolated from a table of intervals for estimates of the binomial parameter by Hald (1952).*

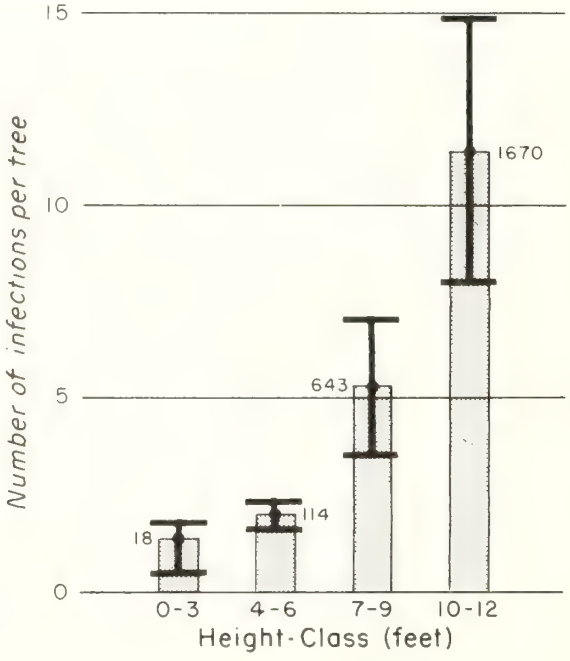

Figure 4.—*Number of infections per infected tree in each height-class, with 95 percent confidence intervals.*

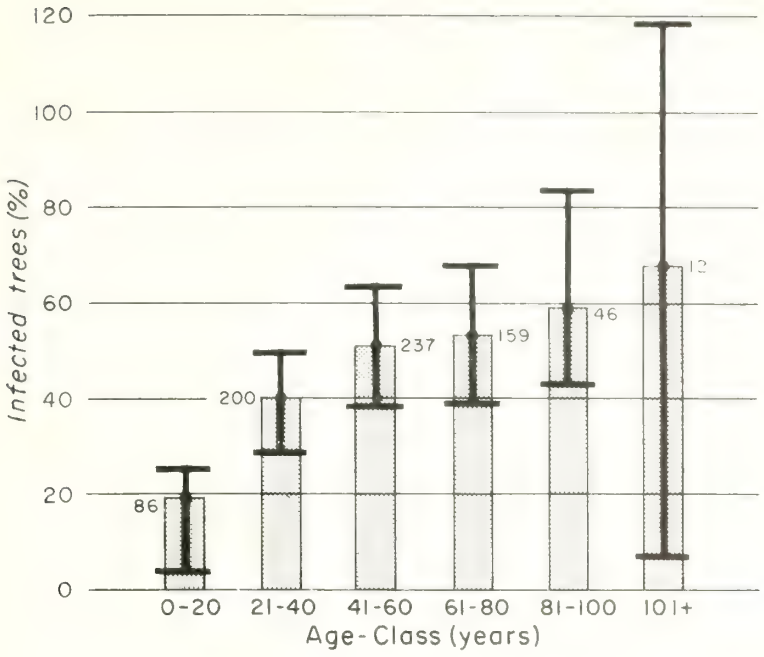

Figure 5.—*Percentage of firs infected in each age-class, with 95 percent confidence intervals.*

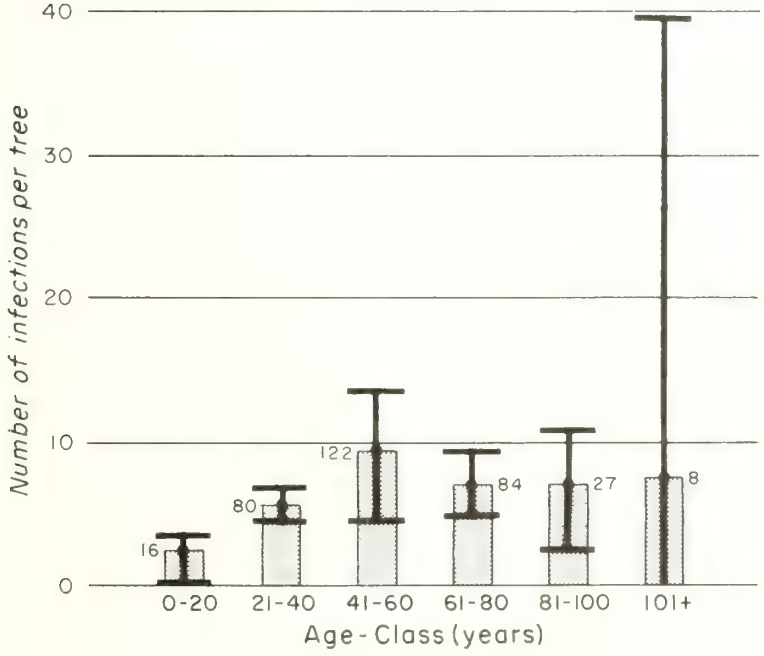

Figure 6.—*Number of infections per infected tree in each age-class, with 95 percent confidence intervals.*

ticularly susceptible to wind breakage. Considerable loss in timber volume and quality results from bole infections.

Incidence of bole infections was directly related to tree height *(fig. 7)*. Only 1 percent of all trees in the 0- to 3-foot height class had bole infections. Only 5 percent of the 4- to 6-foot trees were infected. And in the 6 feet and taller class, the percentage of trees with bole infections appeared to increase markedly.

Except in the youngest age-class, incidence of bole infection appeared to have little relation to age of tree *(fig. 8)*. Trees up to 20 years old were relatively free of bole infections. In all other age classes, the proportion of trees with bole infections remained nearly constant.

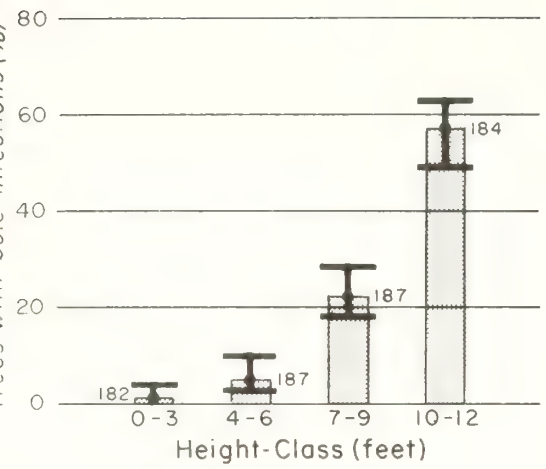

Figure 7.—*Percentage of all trees, by height-class, with one or more bole infections, with 95 percent confidence intervals.*

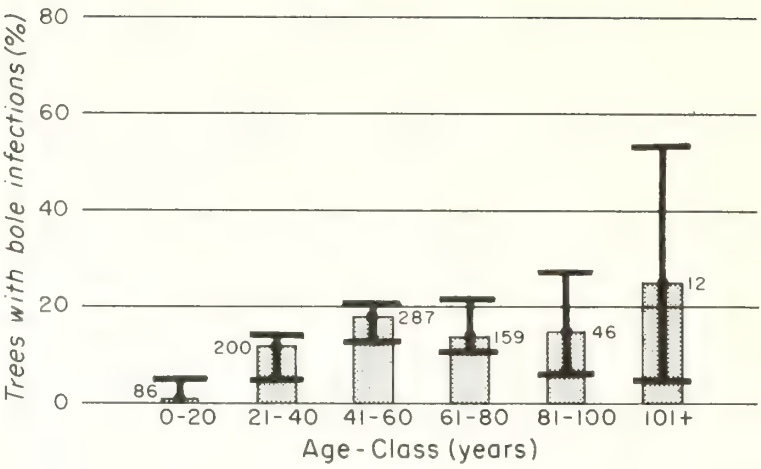

Figure 8.—*Percentage of all trees, by age-class, with one or more bole infections, with 95 percent confidence intervals.*

Discussion

Results of this study agree with those of other investigators (Childs 1963; Hawksworth 1958; Scharpf 1968; and Wicker and Shaw 1967). Infection of understory trees by dwarf mistletoe was directly related either to target area or to tree height. Consequently, the dominant understory trees in a stand were the most severely attacked. Childs (1963) and Wicker and Shaw (1967) considered tree age, or length of time that understory trees are exposed to infection, to be a factor that influenced the infection of conifers. In red fir, I found this factor applicable in only youngest age classes. In trees 20 years or older, age appeared to have only slight influence on percentage of firs infected. And on infected trees older than 40 years, there appeared to be no marked difference in mean number of infections per tree.

Once understory trees become infected, intensification usually takes place from newly established, seed-producing female plants. Probably the greater number of infections on the taller trees can be explained in part by the intensification of the parasite from within the tree crown *(fig. 4)*. But, why the number of infections did not increase strikingly as tree age increased is not fully understood *(fig. 6)*. Perhaps tree vigor—as expressed by height growth rather than tree age—is an important factor in the development of robust female plants and in subsequent intensification by the parasite.

Scharpf and Parmeter (1967) found that the incubation period before infections on red fir become established and are readily visible may be as long as 5 years. Thus, some seemingly uninfected trees may have latent infection. But because tree age appears to have limited influence on infection and because small firs grow only slightly in height in 5 years, the proportion of small trees appearing uninfected but bearing latent infections probably is quite low.

The relationship between tree height and tree age and bole infections was about the same as that to branch infections. This finding was expected because field observations showed that bole infections arise mainly from growth of branch infections into the bole. Only occasionally are they the result of direct infections of the bole. Thus, the more infections that occur on a tree, the more likely the tree will eventually become infected in the bole. Because trees with bole infections usually die, become suppressed, or are of inferior timber quality, forest managers should try to hold dwarf mistletoe to a low level in a stand to avoid bole infection.

The infection that was studied in understory trees occurred in the presence of heavy overstory infection. Under less severe overstory infection or in mixed stands where some screening from dwarf mistletoe occurs, somewhat lower rates of infection of understory stands probably can be expected.

Suggestions for Control

Forest managers are concerned primarily with minimizing the damage from dwarf mistletoe in the residual stand after logging or with preventing the parasite from developing in noninfected stands. From results in this study, I can suggest several approaches to silvicultural control that should help reduce spread of and damage from these parasites in either the residual or in newly established stands.

These approaches to control are based on the knowledge that tree height is related to infection of understory red fir by dwarf mistletoe.

- In infected, pure red fir stands with little understory:

1. Clearcut narrow strips or small blocks of old-growth. Plant the cut areas or allow them to regenerate naturally. Once the new stand is well established and certainly before the trees reach 3 feet in height, return and harvest adjacent infected stands to prevent infection of trees at the margins of the regenerated areas.

2. Harvest infected old-growth stands by selection or seed-tree methods of logging to provide for natural regeneration.

Use as many noninfected trees as necessary or possible as a seed source. If infected seed trees are used and after the area has regenerated naturally but before the understory trees are 3 feet tall, harvest or fell the infected seed trees to prevent further infection of the new stand.

- In infected, pure red fir stands with considerable understory:

Clearcut stands with little regard for saving trees more than 3 feet tall. Sapling and pole-size trees should be "walked down" with heavy equipment or removed in some other manner during or after logging to eliminate the badly infected component of the understory. Avoid leaving any infected overstory unless it is needed for regenerating understocked areas. Immediately after adequate regeneration, remove the infected overstory to prevent further spread of the parasite in the advance growth left after logging.

- In mixed stands where infected red fir is the predominant species:

Harvest the merchantable red fir, leaving the noninfected overstory species as a seed source for regeneration if adequate understory will not be present after logging. Do not attempt to save saplings and poles of the infected species but do, if possible, avoid destroying any of the nonsusceptible understory trees. If infected overstory trees are left as a seed source they should be retained only until the regeneration is well established. If, however, the area becomes regenerated by a species other than red fir, the infected fir overstory can be left in place without fear of infection of the new seedlings.

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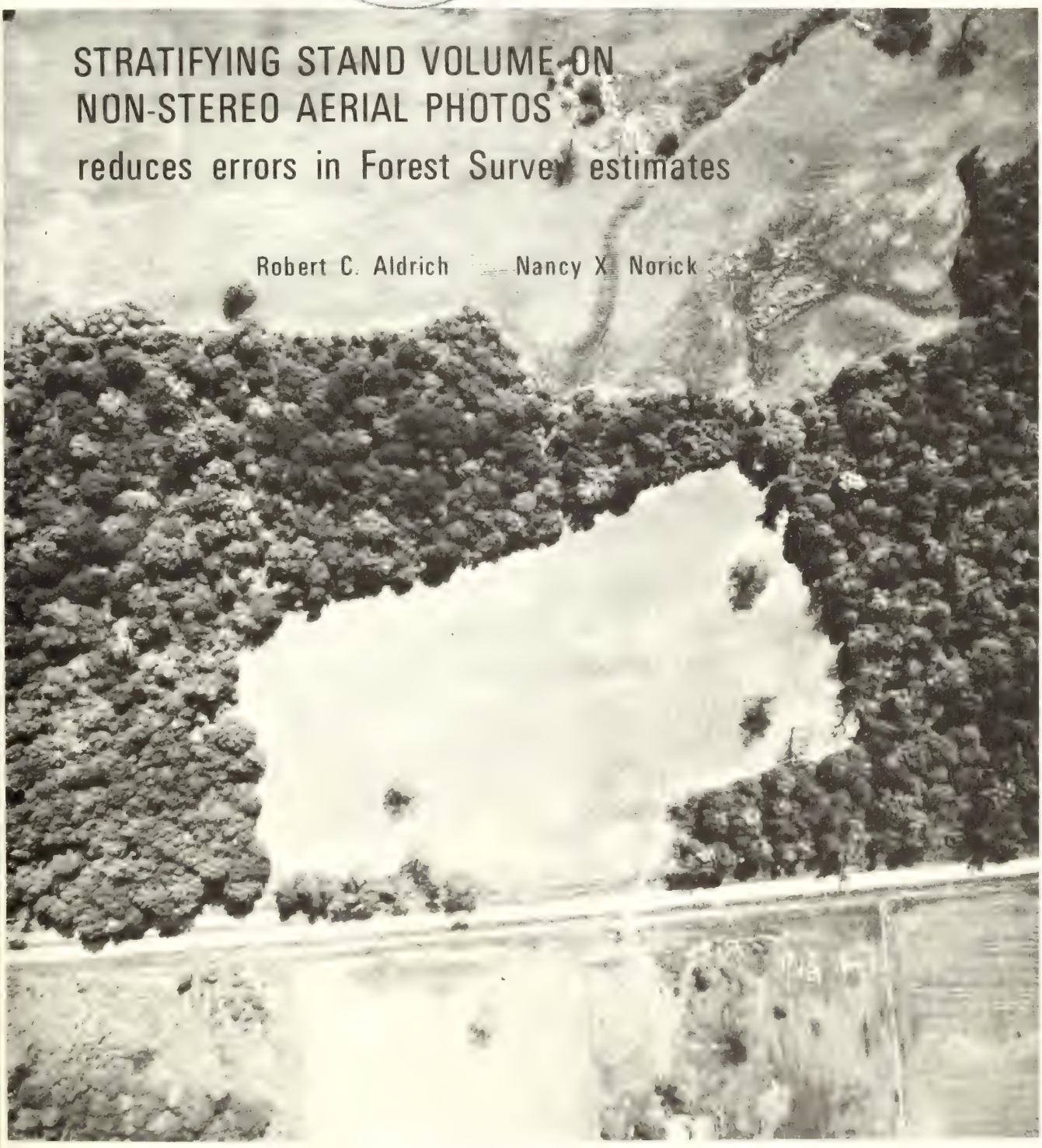
STRATIFYING STAND VOLUME ON NON-STEREO AERIAL PHOTOS

reduces errors in Forest Survey estimates

Robert C. Aldrich Nancy X. Norick



U.S.D.A. FOREST SERVICE RESEARCH PAPER PSW- 51 /1969

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The Authors

are studying problems in remote sensing of the forest environment, with headquarters in Berkeley, Calif. **ROBERT C. ALDRICH** joined the Forest Service in 1948, after earning bachelor's (1944) and master's (1948) degrees in forestry at New York State College of Forestry, Syracuse. After 6 years with the Forest Survey at the Southeastern Forest Experiment Station, he joined the Aerial Research Project at the Beltsville Forest Insect Laboratory, Md. He transferred to the Pacific Southwest Station in 1965. **NANCY X. NORICK,** a native of Cleveland, Ohio, is a 1964 graduate of the University of California, Berkeley, where she majored in statistics. She joined the Berkeley Station staff in 1964, and is now a mathematical statistician.

Classifying forest stand volumes on single aerial photographs is unique to the nationwide Forest Survey[1] — stratifying volume on photographs is not. In fact, since the late 1940's aerial photographs have been used in many classification schemes, including forest and nonforest, forest type, volume, and timber stand size. These classifications are normally made by using stereoscopic viewing techniques. Why? Because most photo interpreters believe that stereo examination improves interpretation and that the addition of measurements of photo stand height is important to photo volume estimates.

Stereo techniques require more photographs to cover a given area. The additional photographs, photo handling, preparations, and the increased interpretation time all result in higher survey costs. If volume could be classified on single aerial photographs with errors equal to or less than in classifications using stereo methods, then survey costs could be reduced.

Many tests of stereo classification schemes have been reported, but we did not find any precedent for nonstereo volume classification in the literature. Of the more recent stereo classification tests, Moessner (1963) compared photo and map stratification schemes for greater efficiency. He found that in volume estimating, photo volume classes offer the best means of stratification. Cubic-foot volume determined by photo measurements and photo volume tables is considered more useful than any other stratification scheme. Estimating commercial forest land area, MacLean (1963) found combined field and photo surveys 6 to 15 times as efficient as field surveys alone. Stellingwerf (1967) found that he could do as well using stereograms to classify volume as with other methods using photo volume tables.

Any of these stratifications will reduce the number of ground sample plots without sacrificing accuracy. As a result, national objectives[2] of accuracy in the Forest Survey for total cubic-foot volume could be met at the least possible cost. But the big question is: "Can single aerial photographs be used to better advantage and improve forest volume estimates in areas where no photo volume stratification is now used?"

This paper reports a study to determine if the efficiency of extensive forest surveys in the southeastern United States could be improved by using photo volume stratification on single aerial photographs. Photo stratification was done after the ground sample plots had been selected, the plots having been selected and permanently established in an earlier survey. This unique situation complicated the problem because variance for stratum proportions estimated after sampling had to be added.

METHODS

The study was made in the Piedmont area of North Carolina *(fig. 1)*. Ten counties were selected to form a continuous block of about 3.25 million acres. Ground volume data were collected on 548 commercial forest locations during the summer of 1964 by using 10-point clusters.[3] To verify photo land use classifications and to measure shifts in land-use between non-forest and forest area, 371 non-forest locations were examined.

Photographic Techniques

The photographs used in the study were conventional U.S. Department of Agriculture,[4] 9- by 9-inch panchromatic 1:20,000 scale prints. The aerial photography was taken 2 to 5 years before the 1964 survey. All permanent ground sample locations were marked on the photographs at the time of the survey.

Forest locations in three counties adjoining the

[1] Forest Survey is a branch in the Division of Forest Economics and Marketing Research, Forest Service, U.S. Department of Agriculture, Washington, D.C. The Forest Survey was authorized by the McSweeney-McNary Forest Research Act of May 22, 1928.

[2] The allowable sampling error in the eastern United States is 5 percent (in terms of one standard error) per 1 billion cubic-feet of growing stock on commercial forest land. The allowable error in the western United States is 10 percent.

[3] Plots were regular Forest Survey field locations for Unit 3, North Carolina. We thank the Southeastern Forest Experiment Station, Asheville, N.C., for the use of this information.

[4] Aerial Photography Division, Eastern Laboratory, U.S. Agricultural Stabilization and Conservation Service, Asheville, N.C.

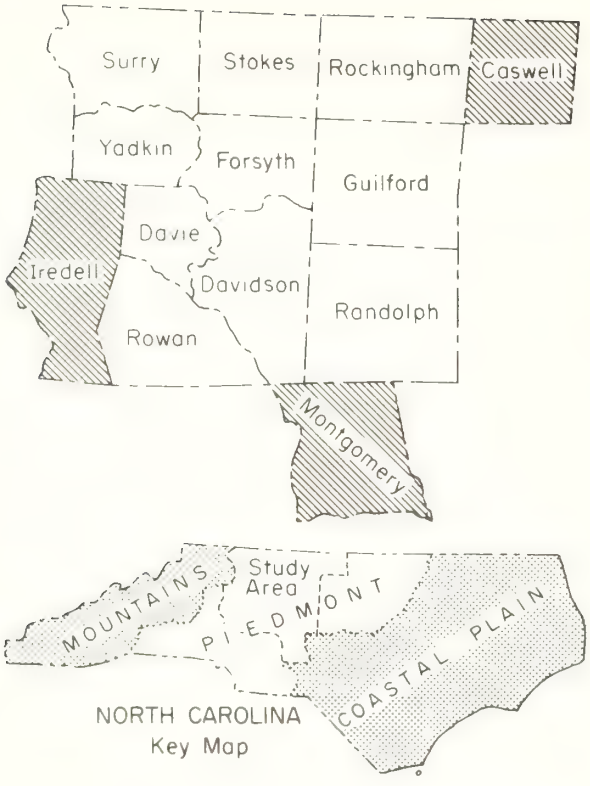

Figure 1.—*The photo volume classification study was made in 10 counties of the Piedmont area of North Carolina. In three other counties, shown by hatch marks, a study was made of photo interpretation techniques.*

study area were used to develop and test photo interpretation techniques *(fig. 1)*. These methods included a cubic-foot volume classification based on crown closure and crown diameter, definitions for three broad forest types, and standards for measuring crown closure and diameter.

Cubic-foot volume classes were defined by studying the distribution of volume in 162 forest locations. By intuition, if we could stratify extremely low and extremely high volume plots by photo interpretation the mean volume variation should be reduced. Since these extremes of volume are easiest to recognize on aerial photographs, our aerial classification scheme was designed to take advantage of this characteristic.

We separated stands into six nonstereo-photo volume classes. Class boundaries were arbitrarily selected by examining the frequency distribution for 162 forest plots in three counties adjoining the study area.

Class	Cubic-foot volume
1	0 (nonforest)
2	1 to 100
3	101 to 400
4	401 to 1,250
5	1,251 to 2,250
6	2,251 +

Forest-type definitions were based upon what a photo interpreter can see best—the visible tree crowns. They were broad classifications—easily arrived at by mentally dividing the visible crown cover into quarters. Since pines are the most readily recognized trees on panchromatic photography, taken in winter and early spring, type definitions were based upon the ratio of pine to hardwood crowns:

- *Pine:* More than 50 percent of the visible crowns in the stand are pine species.
- *Pine-hardwood:* Less than 50 percent but greater than 25 percent of the visible crowns in the stand are pine species.
- *Hardwood:* Less than 25 percent of the visible crowns in the stand are pine species.

Obviously, the height component of stand volume would be difficult to measure on single aerial photographs because of their two dimensional effect. Average crown diameter and crown closure can both be readily measured. They were defined this way:

- *Crown closure:* The proportion of the ground area within a circular 1-acre photo plot covered by the dominant stand. In an unpublished study in 1952, Aldrich found that 10 feet is a good dividing line between merchantable and unmerchantable trees in the southeastern United States. Thus, if there are trees over 10 feet in crown diameter, only these are considered dominant stand. If there are no tree crowns over 10 feet in diameter then trees under 10 feet are considered dominant. Crown closure is expressed as a percent.
- *Average crown diameter:* The average for the dominant stand as defined under crown closure.

A crown closure comparator (Aldrich 1967) was developed to measure average crown diameter and crown closure *(fig. 2)*. This aid is based on nine 10-percent crown closure classes and four 10-foot crown diameter classes. It gives the interpreter a basis for comparing closure standards directly with the photo plot in question. The introduction of crown diameter helps in decisions that are often difficult because of differences in timber size.

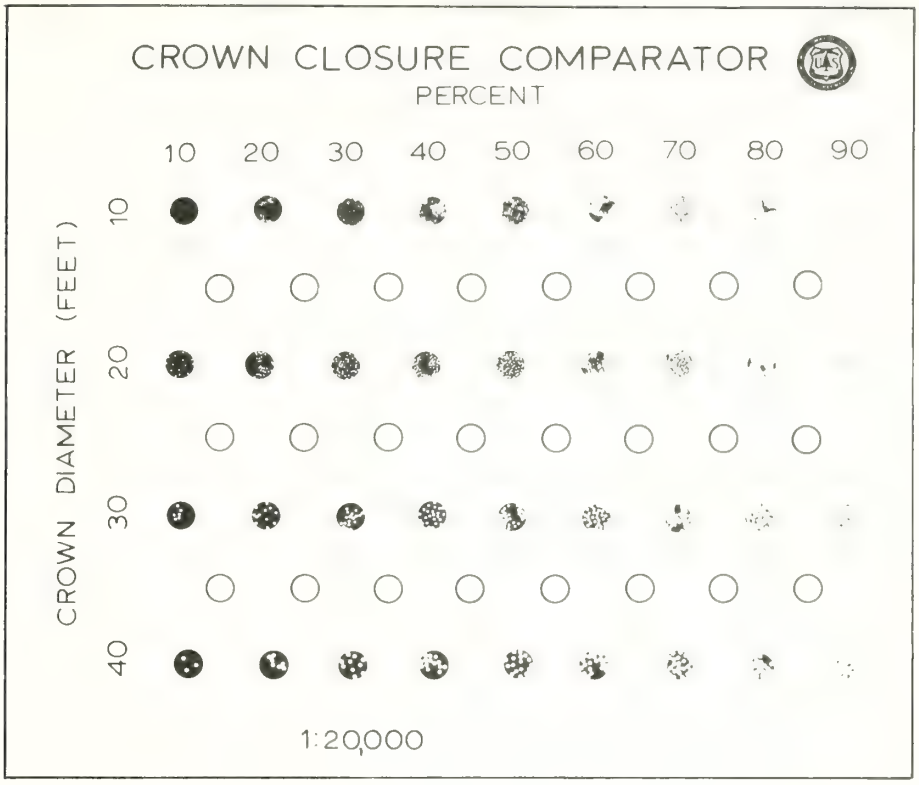

Figure 2.—*The crown closure comparator used for 1-acre forest plots on 1:20,000 scale photographs is normally reproduced as a positive transparency.*

Volume Classification

We had no precedent to follow in using non-stereo photo coverage for volume classifications. Therefore, our first problem was to associate crown closure and crown diameter with stand volume. Forest plots in three counties used for techniques development were classified by forest type, crown closure and average crown diameter. Closure was measured to the nearest 10-percent class, and crown diameter interpreted to the nearest 5 feet. The average crown diameter was plotted over cubic-foot volume measured on the ground for each 10-percent crown closure class *(fig. 3)*. A line was ocularly fitted through the scatter of points, and the five volume classes were delineated on graphs. From the scatter graphs, we developed a cubic-foot volume class table *(table 1)* for use in the 10-county test as the basis for stratifying.

Is there a real relationship among crown closure, crown diameter, and cubic-foot volume and, if so, what is the best equation form to express this relationship? To find out, we tested these parameters using mutiple regression techniques on a computer. Three equations for cubic-foot volume were tested for best fit; for pine type, they are:

$$(1) \quad V = a_1 + a_2(D) + a_3(C) + a_4(C^2)$$
$$(2) \quad V = a_1 + a_2(D) + a_3(C) + a_4(C \times D)$$
$$(3) \quad \text{Log}(V) = a_1 + a_2(D) + a_3(C) + a_4(C \times D)$$

in which: C = crown closure percent and D = crown diameter in feet.

The best equation form was also applied to pine-hardwood and hardwood types, and the multiple correlation coefficients (R) were computed and tested for significance.

Photo Interpretation

To test the accuracy of photo interpretation, we had five photo interpreters examine 548 plots classified on the photographs as forest. They used a 3-power magnifier mounted on a plywood board. Before beginning, the interpreters were instructed in the specifications for identifying forest type and measuring crown closure and crown diameter. They also studied stereograms that illustrated the six non-stereo volume classes *(fig. 4)*. Each interpreter also performed a preliminary test on 60

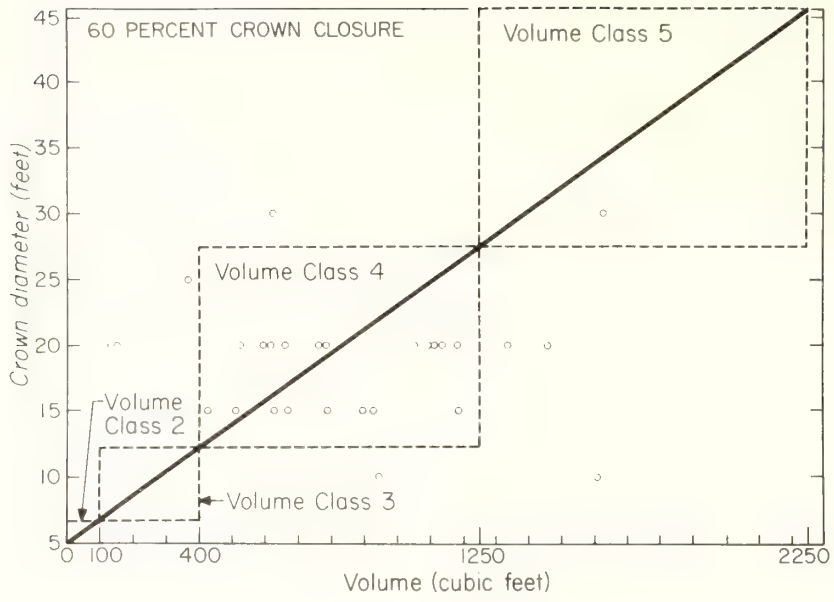

Figure 3.—*Scatter diagram for 60 percent crown closure class shows volume class limits, by crown diameter.*

Table 1.--*Cubic-foot volume class table based on 162 single-photo observations of crown closure and crown diameter*[1]

Crown diameter (feet)	Crown closure (percent)									
	0	10	20	30	40	50	60	70	80	90
	Cubic-foot volume class[2]									
0	1	1	1	1	1	1	1	1	1	1
5	1	2	2	2	2	2	2	2	2	2
10	1	2	3	3	3	3	3	3	3	4
15	1	3	3	3	4	4	4	4	4	4
20	1	3	3	4	4	4	4	4	4	5
25	1	3	4	4	4	4	4	5	5	5
30	1	3	4	4	4	4	5	5	5	5
35	1	3	4	4	4	5	5	5	5	6
40	1	3	4	4	5	5	5	6	6	6

[1]Data outside of outlined area were added empirically to complete table for all possible combinations of crown diameter and crown closure. These data were used by a computer in decision-making.

[2]Class: Volume (cubic-feet)

1	0 (nonforest)
2	1-100
3	101-400
4	401-1,250
5	1,251-2,250
6	2,251 +

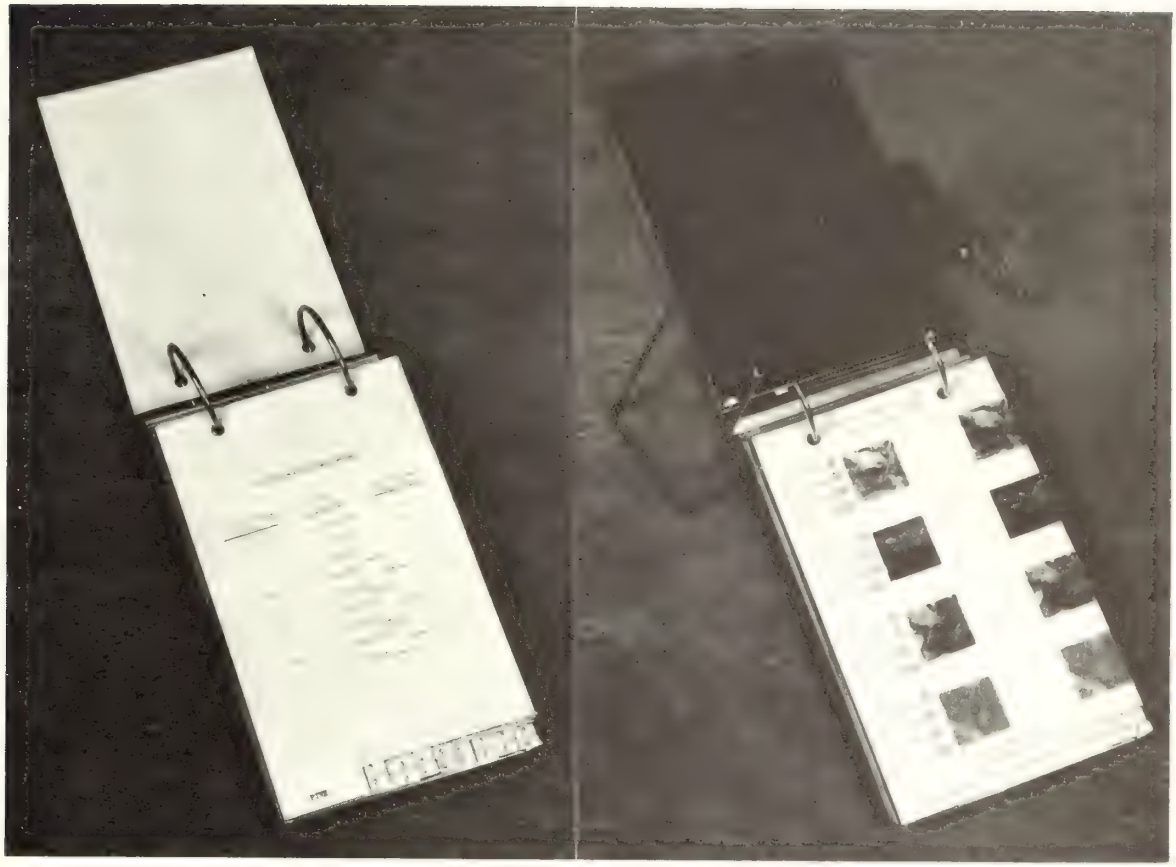

Figure 4.—*Stereogram illustrations for cubic-foot photo volume classes were used in training photo interpreters.*

plots in adjoining counties to check for consistency in interpretation and for conformance with measurement standards. Data for the 548 forest plots provided by the five interpreters were analyzed by analysis of variance.

Non-Stereo Volume Stratification

Stratified sampling can result in great gains in precision under certain circumstances. The method requires that a population be divided into subpopulations, or strata, and that a simple random sample be taken in each stratum. If each stratum is homogeneous, i.e., the measurements of the variable of interest vary little from one another within the stratum, a precise estimate of the stratum mean can be obtained with a small sample. And the estimates can be combined into a precise estimate for the population.

This method is not applicable, per se, to the present problem because the population was not divided into strata before sampling. Therefore, a random sample[5] was not taken within each stratum.

Post-sampling stratification is valid only when the exact proportion of the population falling in each stratum is known (Cochran 1963). If the proportion is estimated from the sample itself, the estimate of the population mean, or total, would be identical with the estimate obtained from simple random sampling. Hence, no gain in precision could be realized. On the other hand, if we estimate the proportions in the strata from an independent photo sample, the variance of the population mean would be greater than for pre-sampling stratification. This is because variance for the estimated proportions must be added to the total. If, however, the strata are homogeneous, we will still have a gain over a simple random sample estimate.

The Forest Survey sampling design in the

[5] The Forest Survey sample is systematic, but random sampling is assumed.

southeastern United States incorporates permanent ground sample plots that were not selected from volume strata. Hence, before a statistical measure of variance can be computed for a survey design using photo stratification after ground sampling, a new variance equation was necessary. This equation included the additional variance added for strata proportions found after sampling:

$$S_{\bar{y}}^2 = \sum_{j=1}^{h} S_j^2 \left(\frac{1}{n} - \frac{1}{M}\right)\left[\Pi_j + \frac{(1-\Pi_j)}{N}\left(1 - \frac{N}{M}\right)\right]$$

$$+ \frac{1}{N}\left(1 - \frac{N}{M}\right)\sum_{j=1}^{h} \Pi_j (\bar{Y}_j - \bar{Y})^2$$

$$+ \sum_j \frac{(1-\Pi_j)}{n^2 \Pi_j}\left[\Pi_j + \frac{(1-\Pi_j)}{N}\left(1 - \frac{N}{M}\right)\right] S_j^2$$

$\bar{Y}$ = population mean of variable Y (net cubic-foot volume)
h = number of strata
n = number of ground plots
n_j = number of ground plots falling into stratum j
N = number of photo plots
N_j = number of photo plots in stratum j
M = number of plots in population
Π_j = proportion of plots in population in stratum j
$W_j = \frac{N_j}{N}$, an estimate of Π_j
S_j^2 = the variance of Y in stratum j
$\bar{Y}_j$ = the mean of Y in stratum j

$$s_j^2 = \frac{\sum_{i=1}^{n_j}(Y_{ij} - Y_j)^2}{n_j - 1}, \text{ an estimate of } S_j^2$$

$$y_j = \frac{\sum_{i=1}^{n_j} Y_{ij}}{n_j}, \text{ an estimate of } \bar{Y}_j$$

$$\bar{y} = \sum_{j=1}^{h} W_j \bar{y}_j, \text{ an estimate of } \bar{Y}.$$

A computer simulation model was made up from data from 919 forest and non-forest sample plots in the 10-county area. Photo interpretation data for one experienced interpreter were used as computer input for the model. The relative efficiencies of various sample designs were examined by using an estimate of the variance and costs of ground and photo plots. This manipulation of the data was made possible by a random plot generator and a series of computer programs.

In this study, we assumed that . . .

1. The 919-plot sample was random and normally distributed.
2. Both forest and non-forest photo plots were considered alike, i.e., they were examined without bias just as they were in the 1964 land-use classification. From this examination they were classed as forest or non-forest. A non-forest plot was considered in stratum 1 or 0 volume.
3. The cost of a forest ground plot was $30.00 and a non-forest plot $1.00.[6] The ground plot cost used in cost comparisons was based on a weighted average of these two figures, or $16.79.
4. The non-stereo photo plot cost was $0.07 as determined from the preliminary studies. It was based on a production rate of 40 plots per hour at an hourly pay scale of $2.80.

The computer was programed to answer these three questions:

1. If costs are held constant, what is the best estimate of variance?
2. If number of ground plots is held constant, what is the cost for reductions in variance?
3. If variance is fixed, what is the optimum combination of ground and photo plots that minimize cost?

The questions were answered for both a 2- and 4-strata classification of volume. The strata are defined as:

	Volume (cu.ft.)
2-strata:	
1 (non-forest)	0
2 (forest)	1 to 2,250 +
4-strata:[1]	
1 (non-forest)	0
2 (forest)	1 to 400
3 (forest)	401 to 1,250
4 (forest)	1,251 +

[1] The 6 strata described under photo interpretation techniques were modified because of an insufficient number of plots in proposed stratum 2 and 6. Plots in these strata were combined with original stratum 3 and 5, respectively.

The effect of forest type strata on variance reduction was also tested.

Non-Stereo vs. Stereo Stratification

Comparing the efficiencies of non-stereo and stereo photo volume stratification for the same population was unique. In this study, we wanted to find out if stand height would improve the efficiency of photo volume stratification. The cost of

[6] Ground plot costs estimated by Joe P. McClure, Forest Survey Project Leader, Southeastern Forest Experiment Station, Asheville, N.C.

a non-stereo photo volume plot was $0.07; a stereo plot cost was $0.17. Thus, the cost of a stereo photo sample design was about two and one-half times that of a non-stereo photo sample. To justify this difference, we had to show a substantial reduction in the Forest Survey sampling error by using stereo classification of volume.

Briefly, these are the steps we followed to prepare the photographs for interpretation:

1. Transferred the 919 photo plots in the study area to stereo photo coverage using a mirror stereoscope.
2. Located principal and conjugate principal points and marked them by a pin prick.
3. Found photograph scale by converting photo enlargement ratio factors furnished by the U.S. Agricultural Stabilization and Conservation Service office in Asheville, N.C., as follows:

   $$\text{Scale} = \frac{1}{R(E)}$$

   in which:

   R = enlargement ratio factor.

   E = enlargement scale in thousands (3960).
4. Fastened photographs in correct orientation with magnets *(fig. 5)* by using a photo alignment guide made of rolled steel on a plywood base. The correct orientation was facilitated by a clear plexiglass alignment rule with two pins 7 inches apart. The pins were placed through the photograph centers and into center holes in the steel alignment guide. Each photograph was rotated until a line connecting the pins on the alignment rule passed through the conjugate principal points. The magnets were placed at the photograph corners and the alignment rule removed.

An Old Delft Scanning Stereoscope was used to help interpret the photographs after they were correctly oriented. Crown diameter and closure were measured by the same standards used in the non-stereo part of the study. Average stand height was defined as the average for the dominant stand. Therefore, if there were trees more than 10 feet in crown diameter, only they were considered the dominant stand. When only trees less than 10 feet in crown diameter were present, they were considered the dominant stand. The total height was expressed in terms of differential parallax measured to the nearest .01 mm. with a Zeiss Stereometer. Differential parallax (dp) was converted to total height (h) in feet using the equation, $h = \frac{(FL \times S) \times dp}{AB + dp}$ in which FL = focal length (.687 ft.), S = scale number (20,000), and AB = air-base in mm. A computer subroutine made this conversion. Forest type was recorded for each plot as previously defined for the non-stereo part of the study.

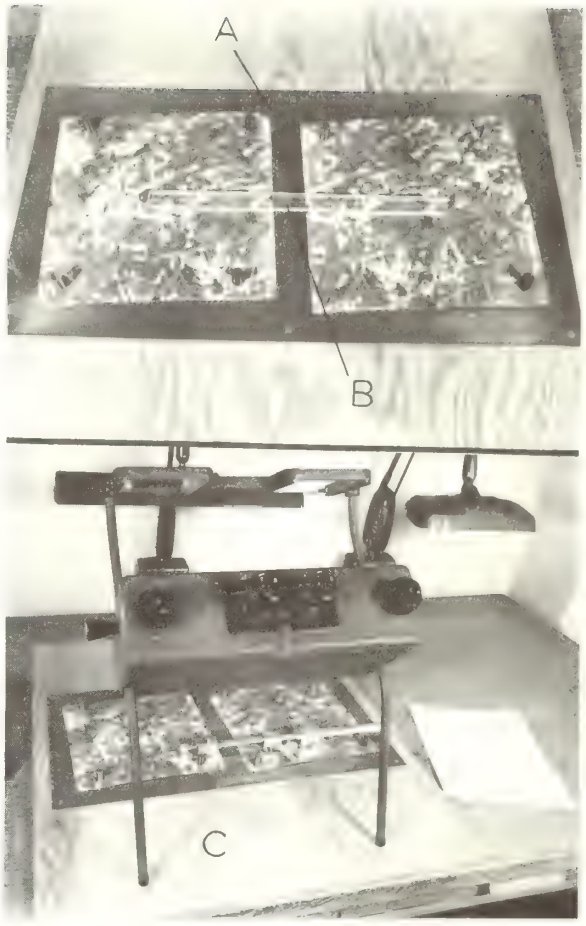

Figure 5.—*A photo alignment guide was developed for rapid orientation of overlapping photographs: (A) rolled steel plate with etched aligned center points; (B) photo alignment rule; (C) two overlapping photographs correctly oriented with Old Delft Stereoscope and Zeiss Stereometer.*

Volume classes were defined as:

Class:	Volume (cu. ft.)
1	0 (non-forest)
2	1-100
3	101-400
4	401-750
5	751-1,250
6	1,251-1,750
7	1,751-2,250
8	2,251-3,000
9	3,000 +

Table 2.--*Stand volume class table for stereo interpretation; 50 foot height class*[1]

STAND HEIGHT--50 FEET

Crown diameter (feet)	Crown closure (percent)									
	0	10	20	30	40	50	60	70	80	90
	Cubic-foot volume class[2]									
0	1	1	1	1	1	1	1	1	1	1
5	1	2	3	3	3	4	4	5	5	5
10	1	3	3	4	4	4	5	5	5	5
15	1	4	4	4	5	5	5	5	6	6
20	1	4	4	5	5	5	6	6	6	6
25	1	5	5	5	5	6	6	6	6	7
30	1	5	5	6	6	6	6	7	7	7
35	1	5	6	6	6	7	7	7	7	8
40	1	6	6	6	7	7	7	7	8	8

[1]Data outside of the outlined area were added empirically to complete the table for all possible combinations of crown diameter, crown closure, and stand height. These data were used by a computer in decision-making.

[2]Class: Volume (cubic-feet)

1	0 (nonforest)
2	1-100
3	101-400
4	400-750
5	751-1,250
6	1,251-1,750
7	1,751-1,250
8	2,251 +

An aerial cubic-foot volume table[7] based on the three components of volume — crown closure, crown diameter, and total height — was converted to a volume class table *(table 2)*. Volume class 9 was combined with class 8 because it was apparent that too few plots would fall in the former class. The volume class table was written into a computer program to stratify photo plots into classes.

RESULTS

Best Volume Relationship

The best relationship among the variables crown closure (C), crown diameter (D), and net cubic-foot volume (V) for pure pine type was expressed by the equation:

$$V = a_1 + a_2(D) + a_3(C) + a_4(C \times D).$$

The multiple correlation (R) for the relationship is .682.

When the equation was used for all forest types it resulted in the following multiple correlation coefficients and levels of significance:

	Number of plots	R
Pine	58	[1] .682
Pine-hardwood	[2] 29	[3] .429
Hardwood	69	[4] .352

[1] Significant if greater than .379 at 5 percent level of significance; significant if greater than .449 at 1 percent.

[2] Insufficient samples.

[3] Not statistically significant.

[4] Significant if greater than .336 at 5 percent level; not significant at 1 percent.

The photographs used in this test were taken in winter. This means that pine crowns were fully resolved and easily separated from hardwoods. Hardwoods on the other hand were in most in-

[7] Aerial stand volume table for southern pine. (Unpublished report on file at Southeastern Forest Experiment Station, Asheville, N.C.)

stances (an exception was white oak) completely leafless and difficult to resolve for measurements. This difference explains why the multiple correlation coefficient (R) for pine was greater than for either of the other two types and why (R) for pine-hardwood was greater than that for hardwood. This relationship will always be true in the southeastern United States, where almost all aerial photography of agriculture is taken in the late fall, winter, and early spring.

Interpreters' Accuracy

Analysis of variance to test crown closure and crown diameter means showed that there was a significant difference among all five interpreters. Duncan's Multiple Range Test was used to compare the means by individual interpreter. In the measurement of closure, only two interpreters were not different from each other in their interpretations. A similar test for crown diameter showed that three interpreters were not significantly different from each other in their interpretations. These results suggest that the effectiveness of nonstereo interpretation may depend largely upon the interpreter.

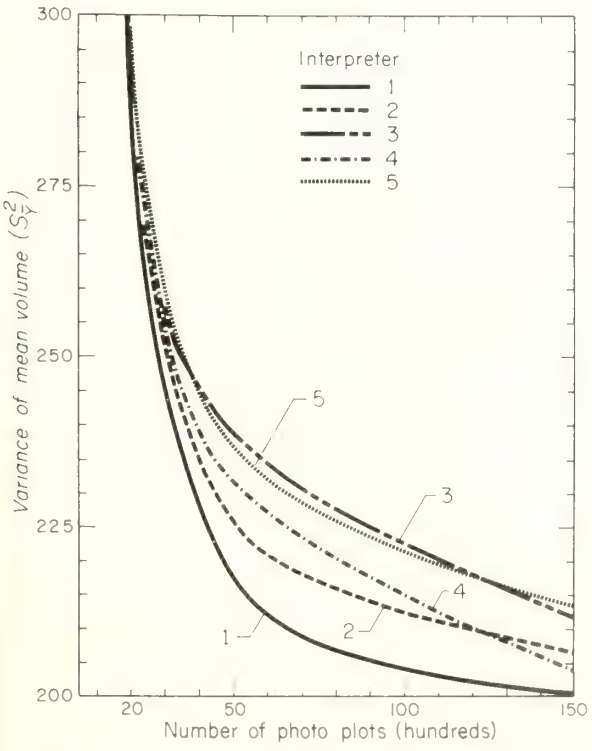

Figure 6.—*Variance of mean volume per acre ($S_{\bar{Y}}^2$) for five interpreters using nonstereo classification shows interpreter differences. A fixed ground sample of 919 plots was examined.*

The abilities of five interpreters to classify cubic-foot volume were compared *(fig. 6)*. Interpreter No. 1 was more familiar with the area than the other interpreters. Moreover, the cubic-foot volume class table was based upon his measurements in the preliminary study. This should have given us greater confidence in his results, but it did not necessarily mean that he was a better interpreter. Despite the dispersion of the curves, the mean volume variance for all five interpreters would be within 17 if 8,000 photo plots were used. All interpreters showed a gain in efficiency over two strata.

Non-Stereo Volume Stratification

The data were first analyzed by forest types. This analysis proved that type strata did not contribute significantly to the reduction of mean volume variance. Therefore, the remaining analysis was done with the data combined. Only data for interpreter No. 1 were used in the analysis.

When the 919 sample plots are treated as a random sample without photo stratification, the mean net volume per acre was 432 cubic-feet, with a variance of 385. The corresponding cost was $15,593.

We held the cost constant ($15,593.00) and introduced two-stage stratified sampling. By varying the number of ground and photo plots, a low variance of 233 cubic-feet was reached by reducing the ground plots to 850 and adding 16,724 photo plots in two strata *(table 3)*. If 4 strata are used, 825 ground plots and 22,784 photo plots would reduce the variance to 206 cubic-feet *(table 4)*.

If the number of ground plots were held constant at 919, changes in the number of photo plots caused reductions in variance *(fig. 7)*. By adding 8,000 photo plots in two strata the variance was reduced to 237. If four strata were used, the same number of photo plots reduced variance to about 210. The added cost for the four-strata method would be $560.

For a fixed variance of mean volume of 206 cubic-feet, we found that 4-strata photo volume stratification did not reduce cost below that for ground plots alone. The optimum sample for the lowest variance at the least cost would require 925 ground plots and 9,370 photo plots at a cost of $16,350. This requirement does not mean that we cannot reduce survey costs by using photo volume

Table 3.--*Comparison of the variance of mean volume per acre* ($S_{\bar{Y}}^2$) *for 2- and 4-strata double sample designs at fixed cost of $15,593*[1]

Ground plots (number)	Photo plots	Variance ($S_{\bar{Y}}^2$)	
		2-strata	4-strata
	Number	*Cubic feet*[2]	
550	89,442	360	312
575	83,382	356	309
600	77,322	326	292
625	71,262	335	280
650	65,203	314	263
675	59,143	315	253
700	53,083	293	244
725	47,023	283	236
750	40,964	278	231
775	34,904	264	226
800	28,844	271	218
825	22,784	251	206
850	16,724	233	217
875	10,665	247	211
900	4,605	256	229

[1]Cost of a simple random sample of 919 one-acre ground plots. Mean volume per acre is 432 cubic-feet with a variance of 385.

[2]Average of six variances.

Table 4.--*Optimum combination of ground and photo plots for lowest variance*[1] *at three fixed cost levels*

Fixed cost (dollars)	Ground plots	Photo plots	Variance ($S_{\bar{Y}}^2$)
	Number		*Cubic feet*
	2-STRATA		
11,965	643	11,211	321[2]
15,593[3]	850	16,724	241
19,491	1,101	11,574	193
	4-STRATA		
11,695	638	12,423	284
15,593	855	15,513	209
19,491	1,099	12,059	171

[1]Average of 10 variances and ground and photo samples around the lowest point.

[2]Mean volume for a simple random sample was 432 cubic feet, with a variance of 385.

[3]Cost of a simple random sample.

stratification. Several combinations of photo and ground plots will reduce the variance of mean volume per acre, costs, or both. For instance, if we are interested in estimating only the mean volume per acre, the number of ground plots can be reduced and photo stratification after sampling used to reduce variance from 385 cubic-feet for simple random sampling to 250 cubic-feet for $13,000—a 17 percent reduction *(fig. 8)*. On the other hand, if we want to keep the ground sample intact to measure growth, timber quality, mortality, and stocking in addition to volume, we can reduce vari-

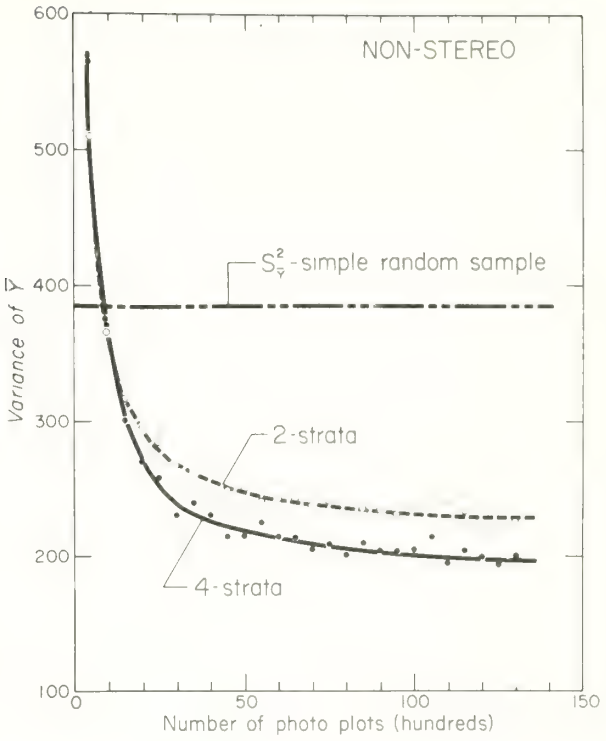

Figure 7.—*By combining 2 or 4 non-stereo photo volume strata with ground sampling, variance can be reduced below that for random sampling with ground plots only. A fixed ground sample of 919 plots was examined.*

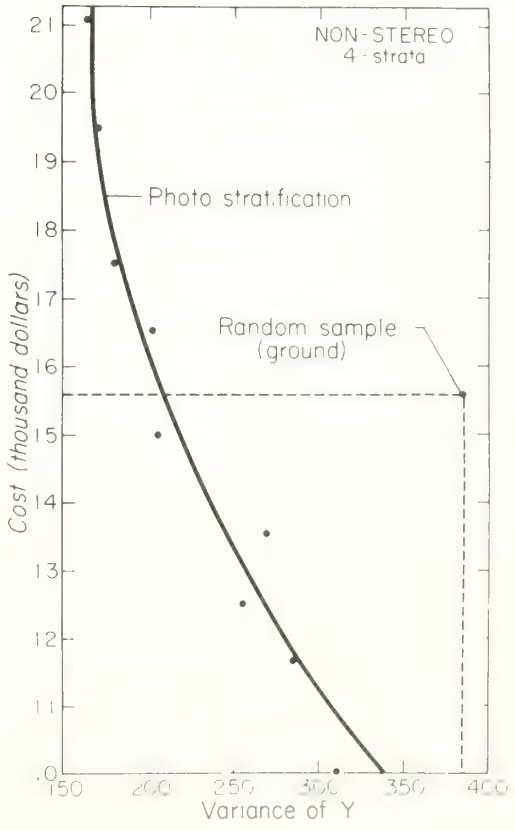

Figure 8.—*The mean volume variance was reduced by using non-stereo photo volume stratification combined with a permanent ground sample. The dashed lines represent the cost and variance for a simple random sample using 919 ground plots.*

ance to 175 cubic-feet by increasing the cost to $18,500—a 19 percent increase. Thus, depending on the survey objective, photo stratification of cubic-foot volume after ground sample selection can be a useful tool for improving forest resource statistics.

Comparison of Two Techniques

A 5-strata stereo photo sampling design increased sampling efficiency over a 2-strata non-stereo design *(table 5)*. But the increase is only slight. The fact that a non-stereo photo sampling design using 4-strata is more efficient than either stereo photo stratifications is of much greater interest. This is only true, however, when survey cost is kept constant at its present level. To keep costs constant would mean sacrificing a number of expensive ground plots (69) to pay for 6,958 stereo photo plots. Thus, we cannot benefit from a stereo volume stratification without sacrificing valuable ground data—unless additional funds are made available to cover the photo sample cost.

By holding the number of ground plots constant at 919 and varying the photo samples up to 12,000, we reduced the variance to 206 for a 5-strata photo design *(fig. 9)*. An 8-strata design with 13,000 photo samples would reduce the variance as low as 198. These reductions in variance would improve the efficiency of the present Forest Survey design only slightly. The volume error for 10 counties would be reduced from 3.60 to 3.26 percent. But this small reduction would cost $2,210.00—a 14 percent increase in survey costs.

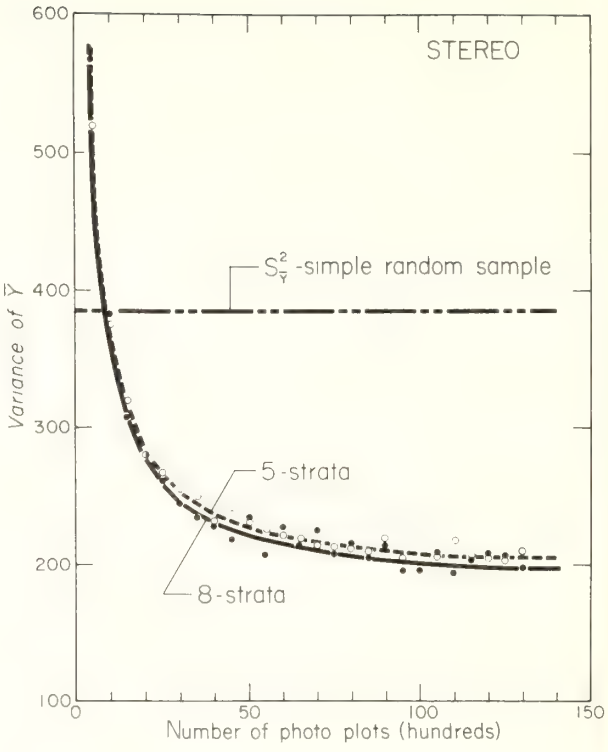

Figure 9.—*Either 5 or 8 stereo photo volume strata combined with ground sampling will reduce variance below that for simple random sampling with ground plots only. A fixed ground sample of 919 plots was examined.*

Table 5.--*Number of ground and photo plots, estimated low variance, and efficiency for non-stereo and stereo photo stratification with survey cost fixed at $15,593*

Photo sample	Ground plots	Photo plots	Lowest variance	Efficiency[1]
	— Number —			
Non-stereo:				
2-strata	850	16,725	241	1.00
4-strata	855	15,513	209	1.15
Stereo:				
5-strata	837	8,270	229	1.05
8-strata	859	6,051	241	1.00

[1]Non-stereo 2-strata (forest, nonforest) photo classification used by Forest Survey in southeastern United States was the base for computing efficiency. (Example: efficiency $= \frac{241}{209} = 1.15$.)

DISCUSSION AND CONCLUSIONS

Why does the addition of height in the stereoscopic model fail to improve stratification by volume density classes? This addition should, by intuitive reasoning, reduce variance estimates considerably because stand height is more closely correlated with stand volume than with either crown diameter or closure. Why there is no improvement can be answered only by speculation.

Regardless of method, non-forest (0-volume strata) was correctly classified about 90 percent of the time. This class represents from 30 to 70 percent of the land area, by county, in the Southeast. Thus, when non-forest is used as a volume strata, it removes a large source of variation and dramatically improves mean volume variance. In this study, the variance for simple random sampling without stratification was reduced from 385 to 241 cubic-feet by using a 2-strata land-use classification. This was a 37 percent reduction. Any gains from other photo strata will be smaller than this reduction because of greater difficulties in making correct interpretations.

One difficulty is the fact that ground volumes for permanent 10-point cluster samples are not always comparable with volumes on circular 1-acre photo plots. Any agreements are more by chance than by correct interpretation. As a result, volume representing the photo class and actual ground volume will vary widely. For example, one combination of photo plot measurements can result in only one volume class; on the other hand volume on the ground might vary from 0 to 3,000 cubic-feet.

Plots cut-over or cleared for other purposes must be considered in the photo stratification. If not, they can result in additional variation; for example, a photo plot with large merchantable volumes on the photo and assigned a volume class of 6 (2,251 cu.ft.+) may represent 0 volume on the ground if it has been cut.

Quality of the photographs will affect interpretation. The photographs used in this study would be rated from poor to good—depending on the county. Poor quality resulted from one of two sources, or both: (1) low resolution(15–20 lines/mm.) aerial camera lenses or, (2) improper printing by electronic dodging printers. Better liaison between the user and the supplier should improve photography. In addition, specifications for aerial imagery in the future should be more rigid and should include the use of high-resolution camera lenses and films. Shorter rephotography cycles will reduce errors caused by changes due to growth, mortality and cutting.

Another problem is that specifications for photo stratification are not adequate. For instance, the relationships between volume and average crown diameter, crown closure, and average total height are not clear. We also need to know how volume is affected by such other parameters as forest type, site, presence or absence of understory vegetation, multiple crown levels, and others.

Although photo sampling using available 1:20,000 scale U.S.D.A. photography might be improved, the greatest improvement will undoubtedly come from a different approach. One possible approach might be to use photo-oriented sampling schemes, such as multiple-stage photo sampling, to supplement the present 10-point permanent Forest Survey ground samples. For instance, simultaneous small- and large-scale photography might permit multiple-stage sampling that would increase the area represented in the sample and improve estimates of volume and area statistics.

This study suggests that volume density can be stratified on single aerial photographs almost as well as by stereoscopic methods. The reduction in mean volume variance ($S_{\bar{Y}}^2$) using stratification after sampling is too small in either case to justify the additional costs and changes in current Forest Survey techniques. These conclusions apply only to the conditions involved in this study, i.e., where permanent ground samples have been selected without stratification and a layer of photo plots is used in resurveys to determine proportionate areas in volume density classes.

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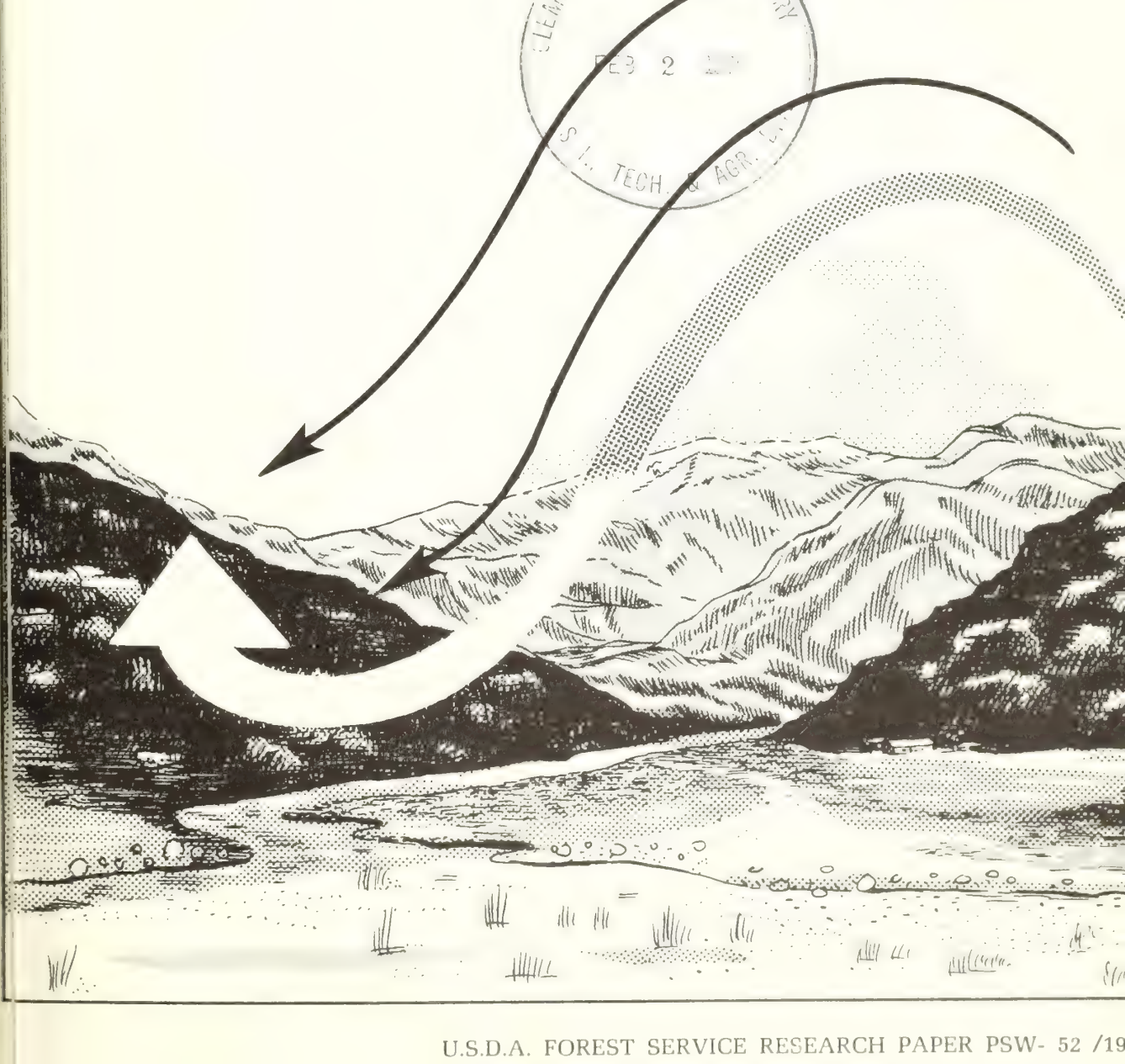

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The Author

BILL C. RYAN, research meteorologist, is studying problems in fire meteorology, with headquarters at the Station's Forest Fire Laboratory, Riverside, Calif. Native of Long Beach, Calif., he earned meteorology degrees at the University of Nevada (B.S. 1950) and Texas A&M University (M.S. 1964). Before joining the Forest Service in 1967, he worked for Meteorology Research, Inc., for 2 years, and was with the U.S. Air Force for 14 years.

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Changes of windspeed and wind direction are of great importance to forest fire behavior. The ability to predict changes in winds can be of vital importance in fire fighting. One of the most significant wind phenomena affecting fire behavior is the foehn wind, which occurs in many parts of the world. Santa Ana winds of southern California are a good example of this warm, dry, downslope wind. Both strong and weak foehn conditions influence the ignitability of fuels and the rate of spread of fires. Strong winds are especially destructive because they induce a high rate of spread. The danger under weak foehn conditions however, is often underestimated. Under weak foehn conditions the wind direction at the zone of convergence (or more properly, confluence) with upslope airflow on the lee side of coastal ridges is extremely variable, making both fire behavior predictions and fire control more difficult. Under these weak foehn conditions on the lee side of coastal ranges very dangerous situations may occur.

The great influence of foehn winds, such as Santa Anas, on fire behavior makes it important to develop better techniques to forecast their occurrence, strength, and duration. Techniques to improve forecasts of a few minutes to several days are needed. A fundamental requirement is knowledge of the relations of location, time, and strength of wind to the synoptic situation. If such relations are established, the forecasting of foehn winds becomes a matter of forecasting synoptic patterns, for which techniques are more advanced and these forecasts are made routinely. But, the relation of the wind to the synoptic situation is complicated, primarily by the effects of topography on wind patterns, which are highly significant in southern California because of the size and variety of topographic features.

The basic large-scale patterns associated with foehn winds have been studied statistically and are quite well defined (Sergius 1952; Schroeder et al. 1964). Fosberg, O'Dell, and Schroeder (1966) studied the three-dimensional structure in two instances of Santa Ana winds on a scale involving the entire Los Angeles Basin. They also present a comprehensive account of earlier studies of both foehn and Santa Ana winds. However, little is known about local and short-time foehn effects, especially in the vertical dimension, although knowledge of these effects is particularly important in fire prevention and control. Few studies of the small-scale foehn effects have been made, primarily because of the cost of maintaining dense networks for small-scale analysis.

The purpose of this study was to develop techniques of small-scale analysis and obtain a more detailed vertical perspective of Santa Ana winds.

Field Study

San Antonio Canyon in the San Gabriel Mountains was chosen for this study of the effects of topography on the vertical variation and distribution of wind velocities. This canyon is highly suitable because of its location to the southwest of the ridge of the San Gabriels and its almost due north-south orientation *(figs. 1, 2)*. Some bends cause perturbations in the wind field and complicate analysis, but as a whole the canyon appears to be close to ideal.

Instrumentation was set up several weeks before Santa Ana conditions occurred and actual field operations could begin. At each weather station we mounted instruments on a 20-foot steel mast. A cup anemometer and wind vane were mounted at 20 feet and a psychrometer, aspirated by an electrically driven fan, was mounted at 4 feet. This system of wind and temperature measuring devices was connected electrically to a timer and a programing set of

relays, which interrogated the instruments every half hour sequentially for windspeed, wind direction, temperature, and wet-bulb temperature. The instruments were also connected to a chart recorder.

Eight weather stations were placed along the canyon in locations I1-I8 *(fig. 1)*. Several considerations made the selection of suitable sites difficult. It was most important that the site have winds and temperatures that were representative of the area. But almost as important, the site had to be protected as well as possible from vandalism. We were only partially successful in meeting either requirement. Observations taken near the recording surface stations suggested that at some of the sites the data were representative of only a small area, and three stations were either stolen or damaged before this part of the study was completed.

Two trailers for rawinsonde (RAWIN) observations were taken to the California Division of Forestry Phelan Station and prepared for quick activation for the field study. A suitable aircraft for carrying sensing and recording instruments was located and contracted to fly on short notification. The four-channel high-precision tape recorder, temperature probe, and pressure transducer were installed, and a test run was made.

Two sites for double-theodolite pilot balloon (PIBAL) observations were established. They were located at P1 and P2 *(figs. 1, 2)*. A third was established at Mt. San Antonio (Mt. Baldy) Notch, but was not used due to lack of personnel.

Field Operation

In January 1968, after the equipment and plans were readied, the 13 persons required for the operation, plus several alternates, were alerted to be ready to move to the field for a 12-hour operation upon a forecast of Santa Ana conditions. The first applicable Santa Ana occurred on February 29. It lasted only a few hours. Two other operations were run before the study was discontinued for the summer. The second operation took place on March 20, 1968, and the third on April 22, but in both cases the Santa Ana conditions dissipated within a few hours so that a prolonged study was not possible. However, sufficient data were gathered to construct streamline analyses and vertical cross-section isentropic analyses.

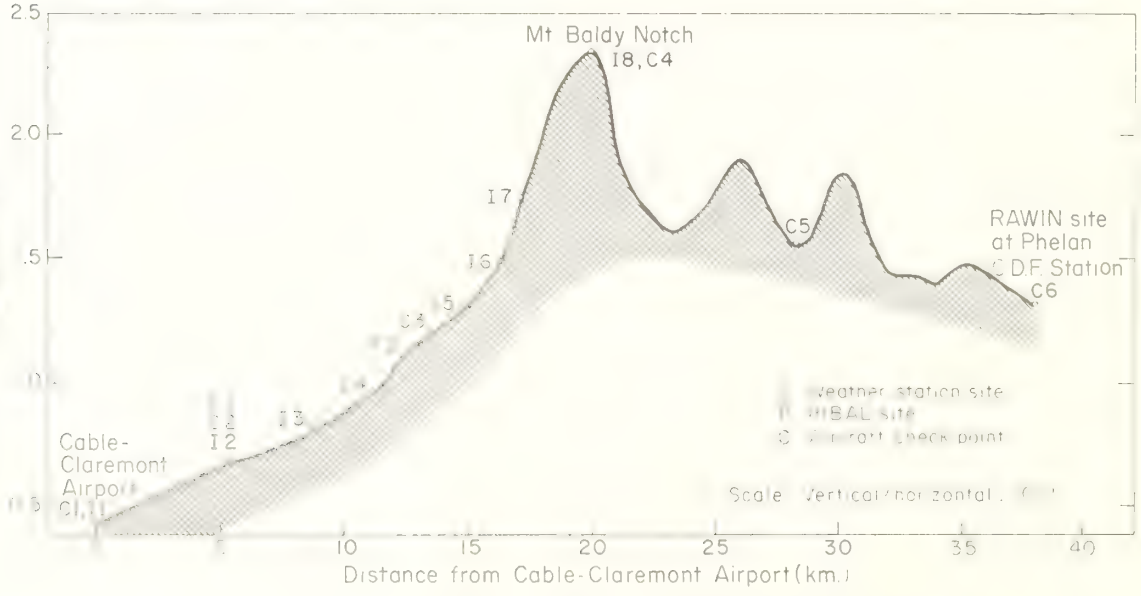


Figure 1.—*Location of weather stations, aircraft checkpoints, PIBAL sites, and RAWIN sites.*

Data Reduction and Analysis

The surface observations that had been recorded on chart paper were read, plotted, and analyzed.

The instrumented aircraft obtained temperatures through a cross section of the atmosphere from Cable-Claremont Airport to the Phelan Station. These cross sections extended from about 10,000 feet to as near the ground as possible. Temperatures and pressure altitudes were recorded continuously on magnetic tape as the aircraft flew along flight paths at 1,000-foot height intervals. At the same time, the observer in the aircraft dictated notes into another channel of the recorder. The recorded comments of the aircraft observer were used to verify the direction of vertical air motion, especially in areas where interpolation was used in the streamline analysis. The observer's reports of turbulence were also often useful to verify the existence of zones of vertical and horizontal shear indicated by the streamline analysis. After the operation, the tape record was transferred to chart paper. The temperature and pressure data were read from the chart paper and entered into the computer for computation of potential temperature and height above sea level. These data were then plotted on vertical cross sections and analyzed.

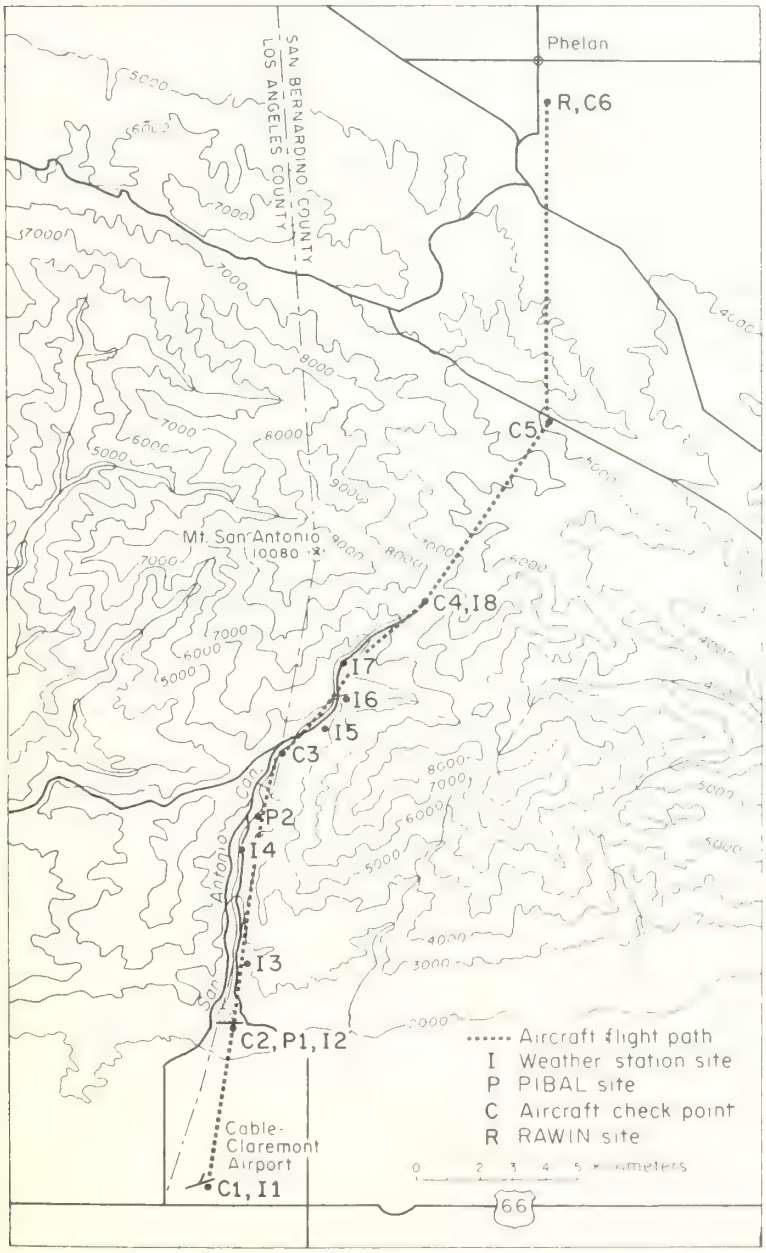


Figure 2.—*Locations of weather stations, aircraft check points, PIBAL and RAWIN sites.*

The rawinsonde data were also punched into cards, and computations of windspeed and wind direction, temperature, and dewpoint temperature were made and plotted against height above sea level by computer. The vertical wind component was determined by calculating the actual vertical velocity less a computed average velocity to the top of the sounding.

The double-theodolite observation recordings on paper tape were read, and the data from the paper tapes as well as the data recorded manually were punched into computer cards. Windspeeds, wind directions, vertical motion, north-south and east-west components of motion, and observational error were determined, by the technique given by Thyer (1962), and windspeed and wind direction were plotted against height by computer. The vertical wind component was determined from the double-theodolite soundings by calculating the actual vertical velocity less the standard vertical velocity used to make single pilot-balloon observations.

Vectors indicating wind velocity in the plane of the vertical cross section were determined from the vertical and north-south wind components obtained from the PIBAL and RAWIN observations. These vectors were plotted on the cross section with the plots of the surface wind observations, and analyzed. Many more PIBAL observations were taken than are reported here, but frequently one or more of the four observers at the two sites had to abort the observation before completion because he lost track of the balloon behind an obstacle. As a result, only a few observations were synoptic or close enough to be used. Fortunately, the similarity of the analyses for the same day indicates that fairly steady state conditions existed on these days. From this evidence, and evidence from the aircraft observer, the assumption can be made that the small differences in times of observations that were used did not cause excessive errors in the streamline and temperature analyses.

Fascimile synoptic charts from the U.S. Weather Bureau were used as the source of information for large-scale weather patterns.

Discussion

In the typical Santa Ana situation, a cold high-pressure system is found at the surface in the Great Basin, so that there are much higher pressures and lower temperatures in Nevada than along the coast of southern California; windflow aloft is relatively strong from the north or northeast. January 19, the day the aircraft instrument test was made, was a good example of Santa Ana conditions. There was a cold, well-developed high pressure center *(fig. 3)* in the Great Basin and a strong pressure and temperature gradient from Nevada to southern California. (Strong winds occurred in the San Gabriel Valley during the day, although they were not plotted on this chart.) The 500-mb. height contours *(fig. 3)* are indicative of the northerly winds that support strong Santa Ana winds. On January 19 there was also a well-defined isentropic pattern *(fig. 4)* parallel to the windflow. This is the typical pattern associated with Santa Ana and lee wave occurrence (Fosberg et al. 1966).

The typical synoptic situation for a Santa Ana seemed to be developing a few days before the date of our first field operation. By the evening of February 26, the movement of the isobaric pattern from the northwest to the southeast indicated that a Santa Ana was possible within the next 2 or 3 days. The high-pressure system centered in southwestern Canada was moving into the Great Basin. The upper-air ridge was increasing in amplitude along the coast of California. The trend continued, and the first field operation was scheduled to begin at 1200 P.s.t. on February 29. The surface high had moved into the Great Basin *(fig. 5, left)* and weak northerly flow developed over southern California. By 1600 P.s.t. the situation had deteriorated. The shift by 1600 P.s.t. of the windflow to southerly and westerly at 500 mb. is shown in figure 5 (right). By 2200 *(fig. 6)* the surface gradient had decreased so that only light winds were observed in the area. Figures 7 and 8 show the streamlines and potential temperature (isentropic) patterns for the afternoon of February 29. (The potential temperature is the same on both figures because only one flight was made on that day.)

The isentropic pattern of February 29 can be compared with the pattern on January 19 *(fig. 4)*, when the aircraft instrument test flight was made. The pattern on January 19 was the typical potential temperature pattern in Santa Ana conditions. The potential temperature pattern on February 29 does not show this characteristic pattern, in which the isentropes are parallel to the streamlines, except to some extent over the Notch. This lack of correspondence between the two patterns is evidently due to the lack of static stability and a nonlaminar temperature field, as shown by the almost adiabatic lapse rate and the nonlaminar isentropic pattern.

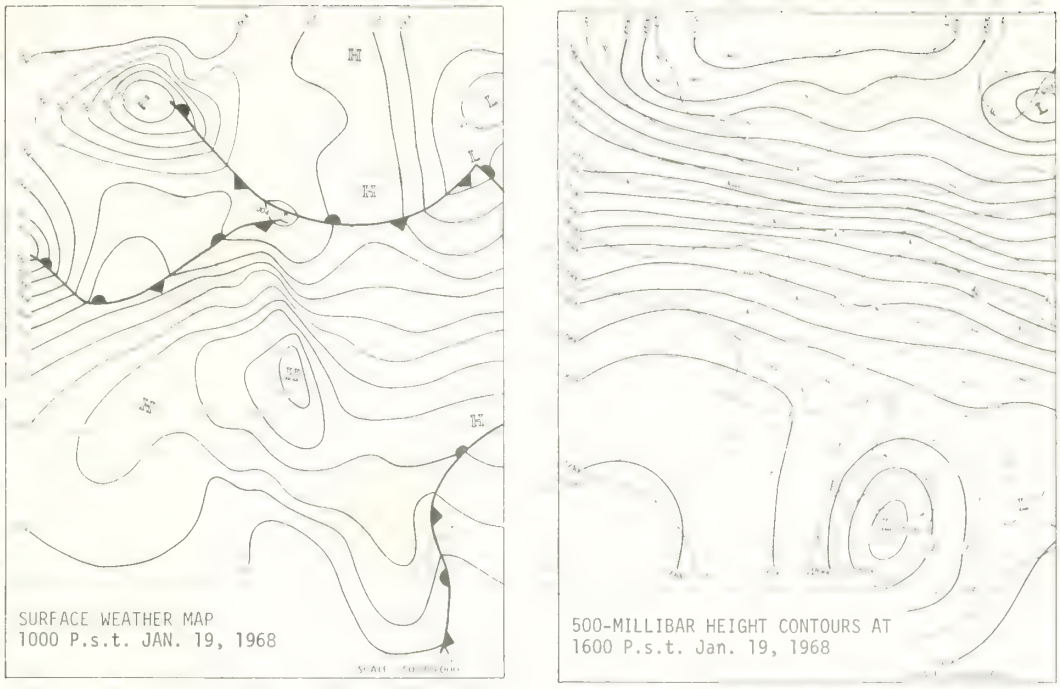


Figure 3. *Surface weather and 500-mb height contours on January 19, 1968.*

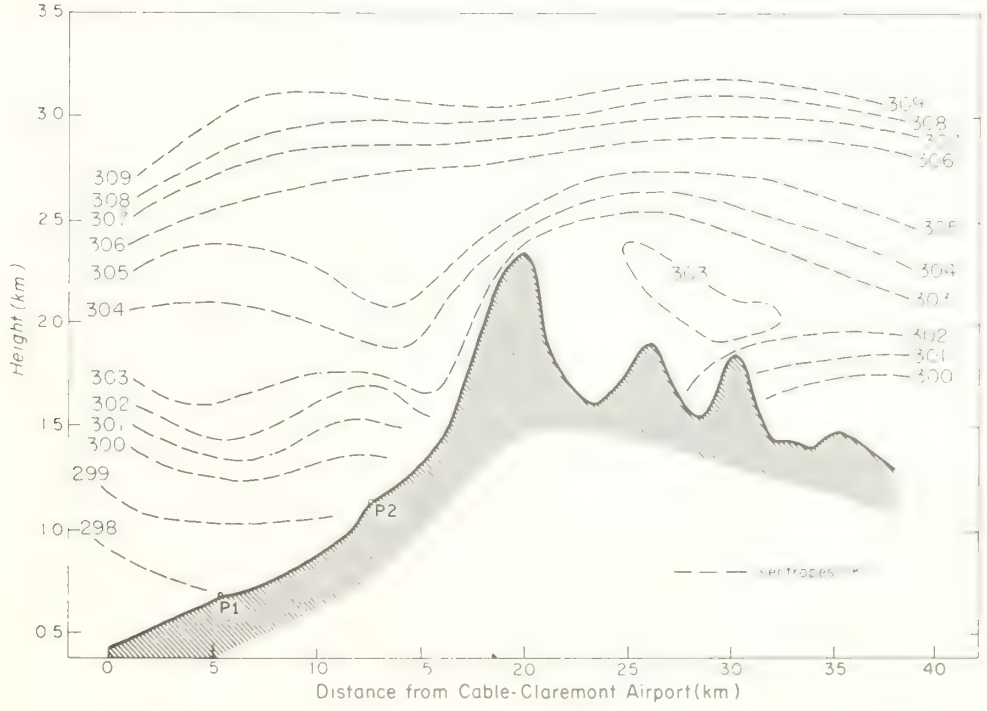


Figure 4. *Potential temperature field obtained by aircraft from 1355 to 1555 P.s.t., January 19, 1968. Potential temperatures are in degrees Kelvin on this chart and on all other charts.*

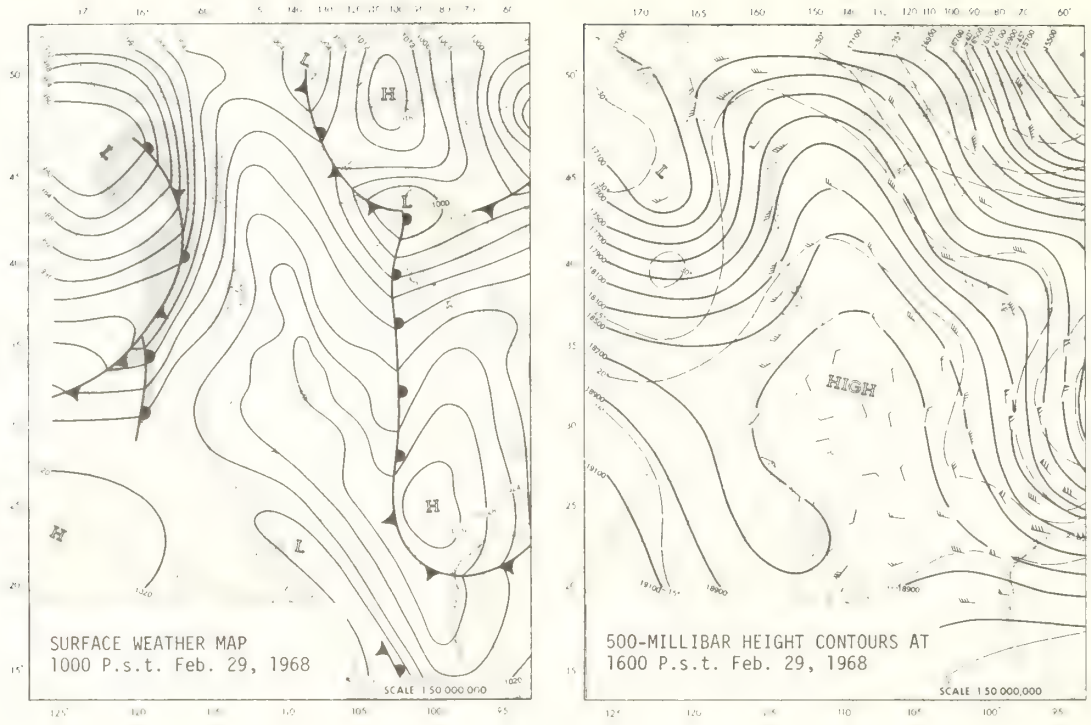


Figure 5.–*Surface weather and 500-mb. height contours on February 29, 1968.*

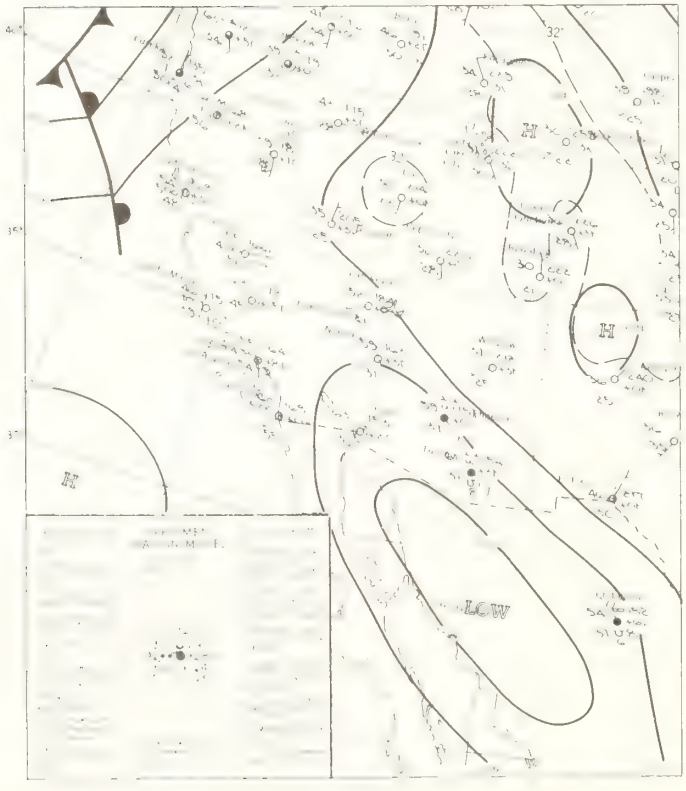


Figure 6.–*Surface weather map and station weather at 2200 P.s.t., February 29, 1968.*

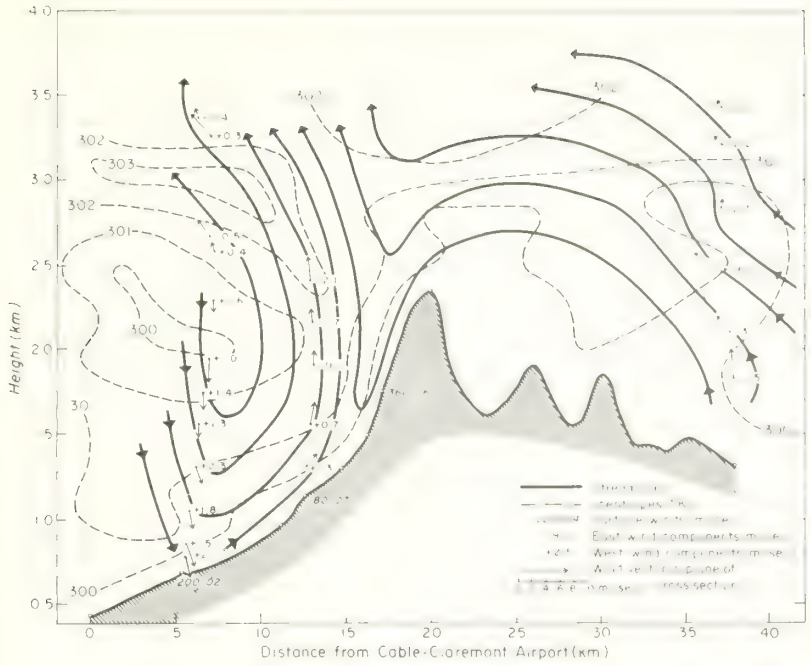


Figure 7.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1300 and site P2 at 1255 P.s.t., surface wind observations near 1300 P.s.t. and RAWIN observations at 1200 P.s.t. Potential temperature field obtained by aircraft from 1154 to 1315 P.s.t. February 29, 1968.*

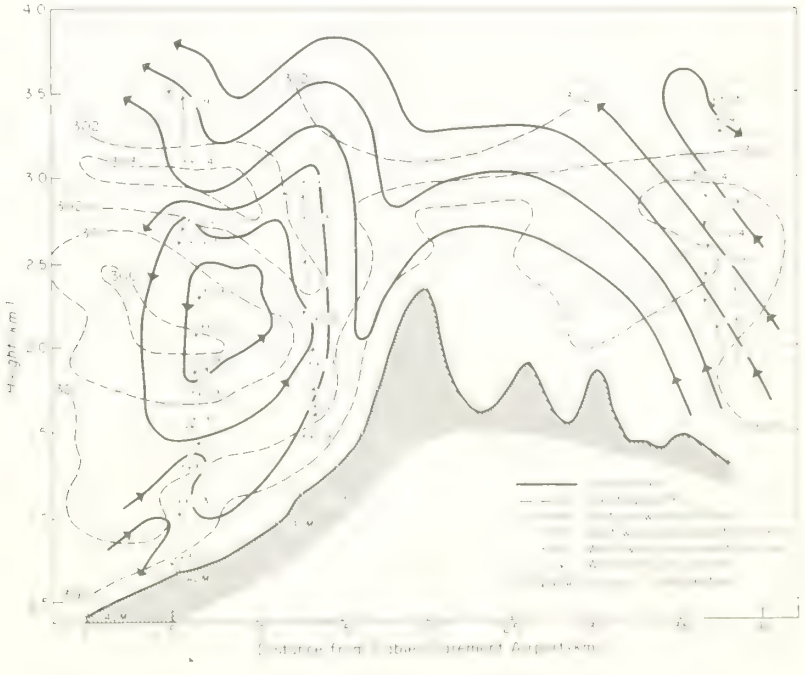


Figure 8.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1502 and site P2 at 1504 P.s.t., surface wind observations near 1500 P.s.t. and RAWIN observations at 1400 P.s.t. Potential temperature field obtained by aircraft from 1154 to 1315 P.s.t., February 29, 1968.*

The potential temperature pattern on February 29 indicated that the atmosphere was not very stable. Potential temperatures showed little or no increase with height, much less than on January 19. The flow on the north side of the range over Phelan was northerly, but no strong Santa Ana winds occurred in the San Gabriel Valley as they did on January 19. This is understandable in that lee waves are associated with stable atmospheric conditions (Scorer 1949) such as occurred on January 19. The striking characteristics of the flow on February 29, as on the other two days of operation, are the penetration of the air into the canyon as it comes over the crest of the range, and the sharply defined zone of converging winds. The movement of the zone evident in a comparison of the 1300 P.s.t. analysis with the 1500 P.s.t. analysis is interesting. The weakening of the flow is reflected in the greater penetration of the south wind on the south side of the slope later in the afternoon. Under situations such as this, the light winds pouring over the crest of the range from the offshore direction react strongly with air moving up the valley from the onshore direction. It is evident that a slight rise or lowering of the airflow pattern can cause rapid change in windspeed and direction. One can also see how rapid change in temperature and dewpoint temperature may accompany these changes in windflow.

The three-dimensional flow in the area from the lower PIBAL site to the C.D.F. Phelan Station can be determined by considering the vertical and north-south flow, indicated by the vectors on the cross section, and the east-west flow, indicated beside the wind vectors. For instance, in the early afternoon of February 29, as shown in figure 7, the flow over the dam was descending from the southwest. This flow was evident from near the surface to near 2.4 km. Above 2.4 km. the flow ascended with little horizontal component. Over the upper site the flow was ascending from the southwest. This flow was evident up to about 1.8 km.; then the flow became easterly. Over Phelan the flow was ascending from the northeast.

The second field operation was on March 20. This Santa Ana situation set up in quite a different way from that of February 29. The strong winds aloft were established in southern California by March 18. These northeasterly winds were associated with a strong trough to the east of the area *(fig. 9)*. The surface pressure gradient was not established until March 20, and even then did not reach great enough strength to cause strong winds *(fig. 10)*. Winds on March 20 were stronger than on February 29 and a deeper lee trough formed *(figs. 11, 12)*. There was

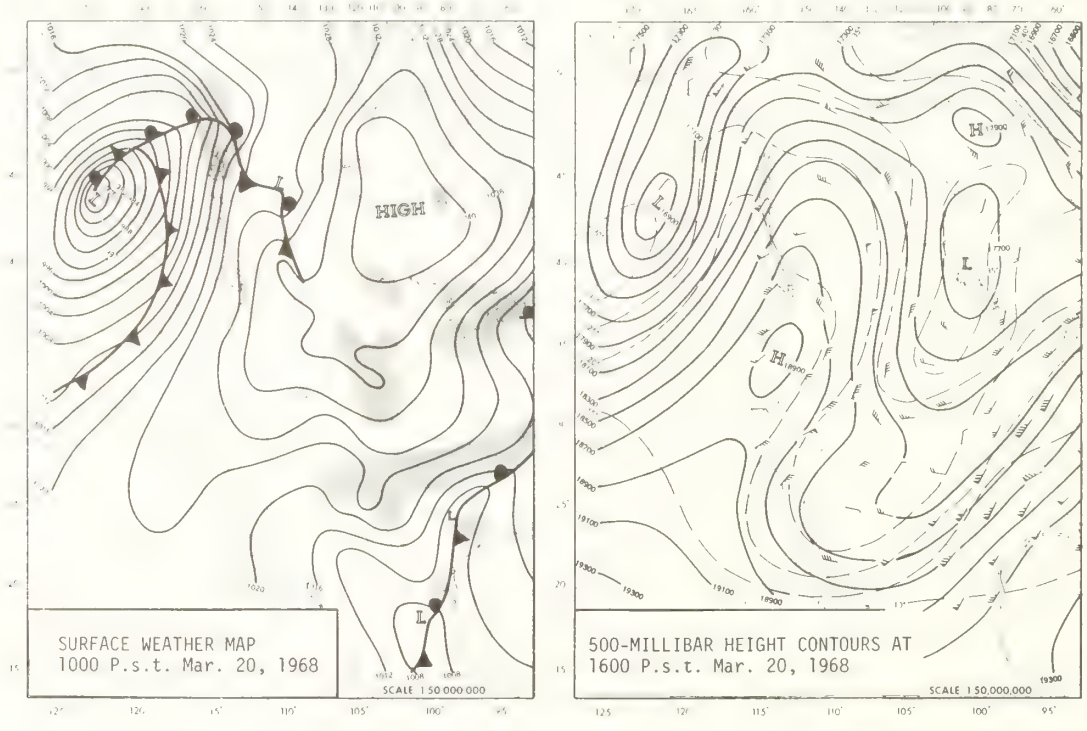


Figure 9.—*Surface weather and 500-mb. height contours on March 20, 1968.*

little movement of the trough between the time of the first observation at 1400 P.s.t. and the observation at 1700 P.s.t., but a great change occurred at San Antonio Dam, where the surface winds changed from 160° at 4 m./sec. to 340° at 9 m./sec. The cross-section analyses show how the vertical eddy changed to cause the reversal of flow. Examination of the isentropic pattern shows an almost unstable condition. There was little increase in potential temperature with height. Above the surface layer both at 1400 P.s.t. and 1700 P.s.t. there was a sudden change of horizontal wind direction between PIBAL site 2 and site 1. For instance, at 1400 P.s.t. at 2.2 km., winds were from 054° at 15.9 m./sec. at site 2, but 304° at 1.8 m./sec. at site 1.

On April 20 it appeared that there was a good chance of Santa Ana conditions within the next two days. A cold front passed through the western part of the country in the morning, followed by a short wave trough. This is the fairly common sequence of development of Santa Ana winds. The trough aloft moved over southern California and established strong northerly winds aloft. The cold surface high-pressure system finally built up in the Great Basin on April 22, to be wiped out a few hours later by another cold front. Comparison of figures 13 and 14 shows how fast the high-pressure system built up. It broke down just as fast. By the following day, April 23, the front was lying across the Great Basin where the high center had been.

The winds reported by the rawinsonde unit at Phelan at 1200 P.s.t. *(fig. 15)* and 1450 P.s.t. *(fig. 16)* on April 22 were strong and northerly. At 1200 P.s.t. the wind at 3.3 km. was 350° at 11.8 m./sec.; at 1450 P.s.t. the wind at 3.4 km. was 348° at 12.7 m./sec. At both times there was a large vertical component to the wind. The lee trough was again noticeable over the upper double-theodolite site at the times of both analyses on this date. Little convergence was shown by these observations at the upper levels, but there was a large vertical shear of winds in the lower levels.

The wind was southerly at and just above the lower PIBAL site, but the 1.8 km. level above the site, the winds were northerly. At the upper site the wind became northerly below 1.4 km. Similar vortices were evident at the times of both analyses on April 22. It appears that this pattern moved from over the dam up the canyon to a position almost over site P2 between 1330 P.s.t. and 1500 P.s.t. With this movement, the lee trough also retreated up the canyon. At both times the lee wave penetrated only deep enough to influence the surface winds very slightly. No winds recorded on the surface along the canyon showed much northerly component.

Figure 10.—*Surface weather map and station weather at 2200 P.s.t., March 20, 1968.*

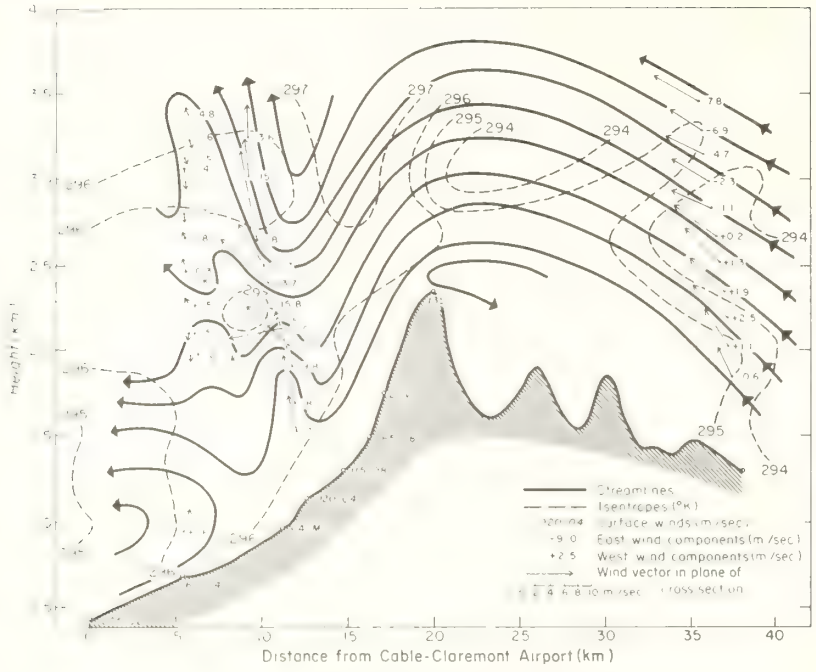

Distance from Cable-Claremont Airport (km)
Streamlines
Isentropes (°K)
Surface winds (m/sec)
-9.0 East wind components (m/sec)
+2.5 West wind components (m/sec)
Wind vector in plane of cross section

Figure 11.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1359 and site P2 at 1400 P.s.t., surface wind observations near 1400 P.s.t. and RAWIN observations at 1450 P.s.t. Potential temperature field obtained by aircraft from 1211 to 1336 P.s.t., March 20, 1968.*

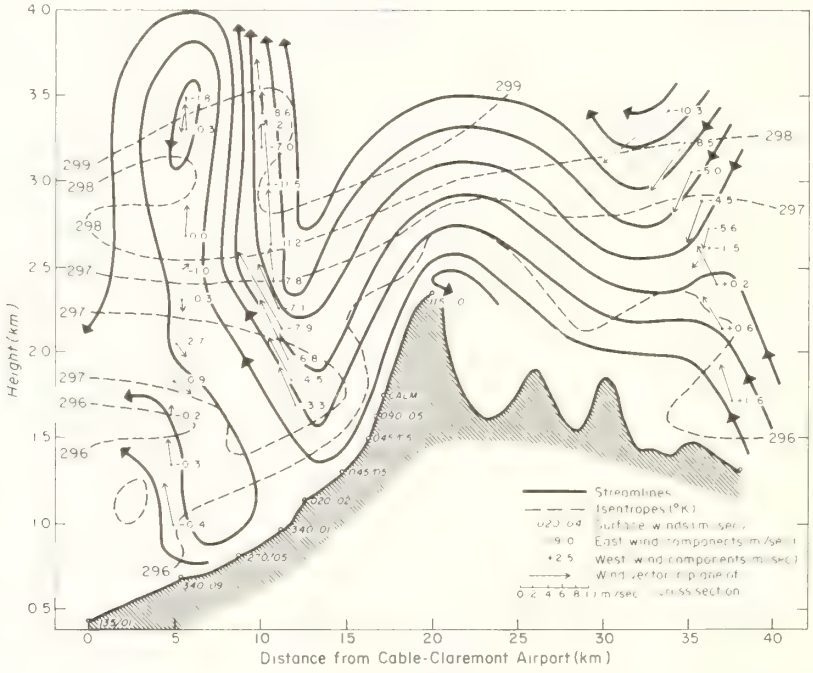
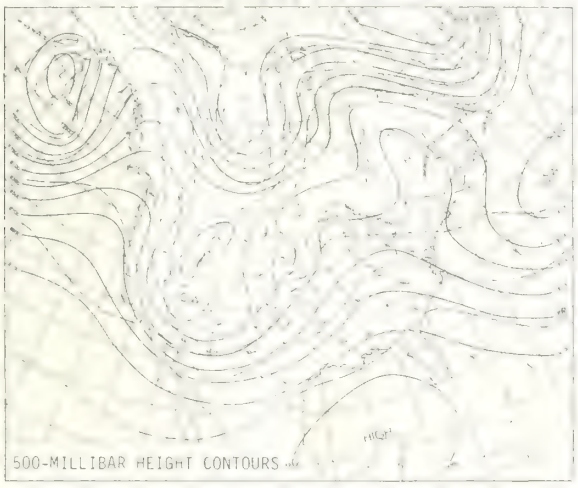


Figure 12.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1659 and site P2 at 1700 P.s.t., surface wind observations near 1700 P.s.t. and RAWIN observations at 1800 P.s.t. Potential temperature field obtained by aircraft from 1615 to 1734 P.s.t., March 20, 1968.*

Figure 13. *Surface weather map and 500-mb. height contours, 0400 P.s.t., April 22, 1968.*



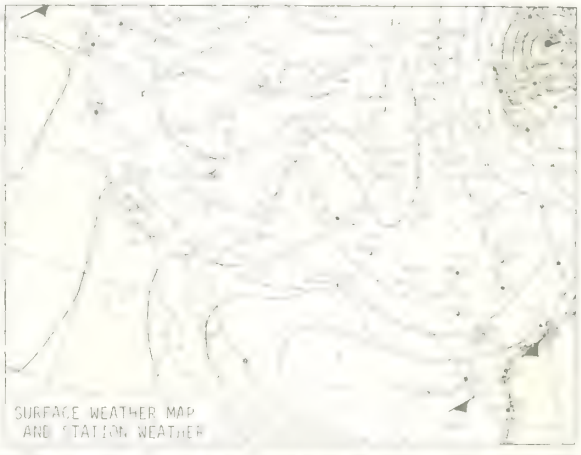


Figure 14.–*Surface weather map and 500-mb. height contours, 0400 P.s.t., April 23, 1968.*

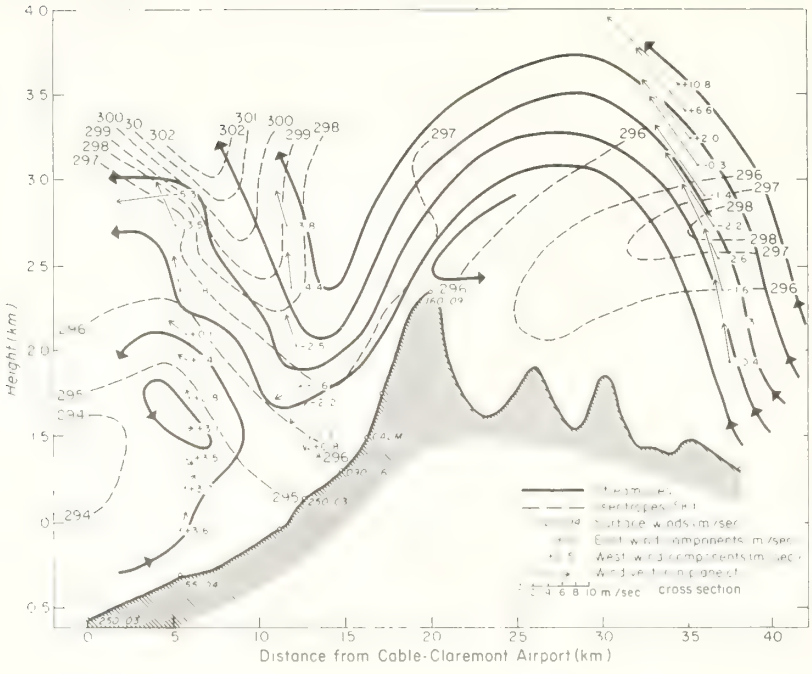


Figure 15.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1325 and site P2 at 1330 P.s.t., surface wind observations near 1330 P.s.t. and RAWIN observations at 1200 P.s.t. Potential temperature field obtained by aircraft from 1200 to 1317 P.s.t., April 22, 1968.*

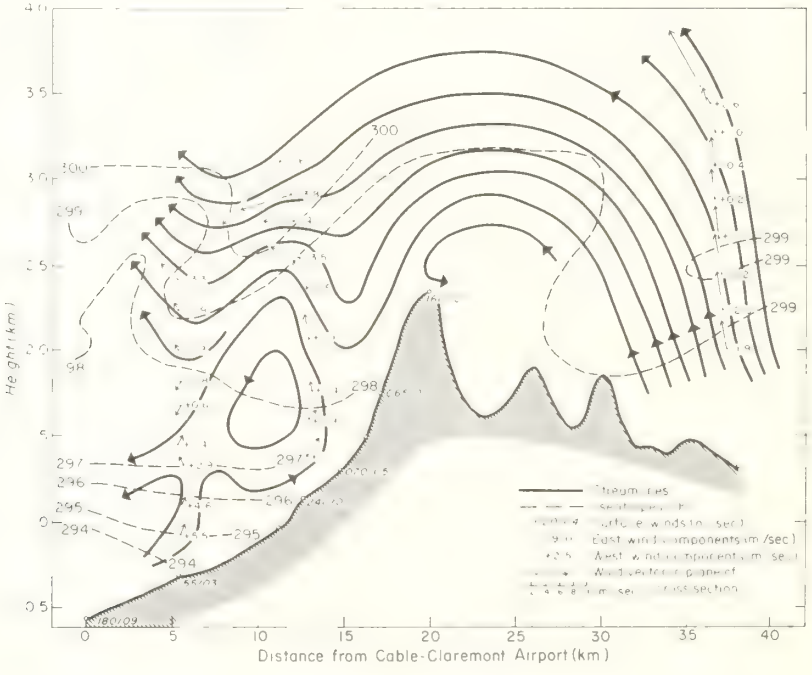


Figure 16.—*Streamline analysis from double-theodolite PIBAL observations at site P1 at 1500 and site P2 at 1500 P.s.t., surface wind observations near 1500 P.s.t. and RAWIN observations at 1450 P.s.t. Potential temperature field obtained by aircraft from 1615 to 1735 P.s.t., April 22, 1968.*

Conclusions

The cross-section analyses of the 3 days of weak Santa Ana conditions reveal how rapid changes in windspeed and direction may occur under these conditions. The analyses indicate the significant dip of the wind field down the lee side of the range even under relatively light wind conditions, and show how opposing wind systems interact on the lee side to allow rapidly changing surface winds. The well-defined convergence zone and the vertical wind field are obvious.

The perspective derived from these cross-section analyses can give fire weather and fire behavior forecasters a greater insight into wind field variations, and give them a better grasp of the reasons for the complexities of surface wind variations.

We plan to continue the study to investigate Santa Ana winds and foehn winds in other areas under varying strengths and conditions. With more data we can establish a closer relationship of synoptic parameters to Santa Ana winds and the surfacing of lee waves, and on this basis, make more accurate forecasts of wind and wind shifts as a function of topography. We can also determine the relationship of wind field to temperature field under varying atmospheric conditions, and thus better determine wind fields from temperature fields, which are more easily measured. These data and data collected in the future will also be used to develop mathematical models based on atmospheric stability, wind pressure, and temperature fields. With these models, fire weather and fire behavior forecasters will be able to predict fire behavior more objectively.

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SILVICAL CHARACTERISTICS OF CALIFORNIA BLACK OAK

(Quercus kelloggii Newb.)

Philip M. McDonald

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The Author

PHILIP M. McDONALD is doing research on silviculture of Sierra Nevada forest types, with headquarters at Redding, Calif. A native of Seattle, Washington, he holds bachelor's (Washington State University, 1960) and master's (Duke University, 1961) degrees in forestry.

Cover: This venerable monarch, growing near Shingletown, Shasta County, California, is 121-feet tall, 16.4 feet in circumference at breast height and is 180 years old.

California black oak *(Quercus kelloggii* Newb.*)* excels all other California oaks in volume (Dickinson 1958), distribution, and altitudinal range. Yet this deciduous hardwood has had little commercial use even though its wood closely resembles that of its valuable, heavily used counterpart—red oak—in the eastern United States. Grain and figure make California black oak attractive for paneling and furniture; its hardness and finishing qualities, for flooring; its strength properties, for pallets, industrial flooring, and other uses (Malcolm 1963).

First collected in 1846 near Sonoma, California, by Karl Hartweg, an explorer of the London Horticultural Society (Jepson 1910), the species was not described until 10 years later by John Torrey. In 1857, John Newberry renamed it *kelloggii* in honor of Albert Kellogg, a pioneer California botanist and physician (Kellogg 1882). In later botanical works, the species was called *Q. californica,* commonly Kellogg's oak. These names have long fallen from favor and today the species is generally known by but one common name: California black oak.

The first known introduction of the species to other countries was in 1878, by an English earl who had visited California. Thirty-two years later Elwes and Augustine (1910) described the trees as 30 feet tall and growing robustly.

California black oak has a north-south range of about 780 miles *(fig. 1).* In Oregon, its natural range extends from just north of Eugene southward through the valleys west of the Cascade Range. It is especially frequent along lower slopes in semi-arid sections of the Klamath and Cascade Mountains but never grows near the Pacific Ocean. In California, the species is found in the northern Coast Range from the Oregon State line to Marin County and then intermittently in the Santa Cruz and Santa Lucia Mountains. It becomes more common on the San Bernardino, San Jacinto, and Agua Tibia Mountains, extending to just south of Mt. Laguna but not reported in Baja California.[1] In California's Sierra Nevada, the species grows abundantly along the west side, from Lassen Peak to near Kings Canyon. It then becomes intermittent southward to the Tehachapi Mountains, where it becomes more abundant. California black oak is generally confined to the westside, but a few stands have been found along the eastside of the Sierra Nevada. It approaches the Nevada State line northeast of Beckwourth Pass but is not reported in Nevada.

HABITAT CONDITIONS

Climatic

California black oak grows in a climate having hot dry summers and cool moist winters. Average annual precipitation varies widely. In the southwestern Oregon valleys, it exceeds 30 inches (Sternes 1960); in northwestern California, from 30 to 100 inches; and in northeastern California, 12 to 15 inches—the lowest amount in the natural range of the species. Throughout the range of black oak in north central and central California, annual precipitation averages 40 to 70 inches, although it may exceed 115 inches locally. Here less than 4 percent of the yearly precipitation falls from June through September. In the southern mountain ranges, precipitation averages about 36 inches. Data on average annual snowfall are incomplete, but black oak grows where snowfall ranges from 0 to 80 percent of total precipitation. In black oak's zone of maximum development, snowfall accounts for 10 to 50 percent of the year's precipitation.

Average mean daily temperatures range from 31°F. to 46°F. during January and from 66°F. to 82°F. in July. The last killing spring frost usually occurs between March 15 and June 9, and the first killing frost in fall comes between August 30 and November 30. The number of days free of killing frosts ranges from 82 to 270 (Sprague 1941; U.S. Weather Bureau 1965). Over an 18-year period, the maximum temperatures recorded at a 3,700-foot elevation in the center of black oak's zone of maximum development was 103°F.; the minimum was 5°F. The maximum number of frost-free days was 215 and the minimum was 116 (U.S. Weather Bureau 1949-1967).

[1]Personal correspondence with Ira L. Wiggins, Biology Department, Stanford University, April 21, 1966.

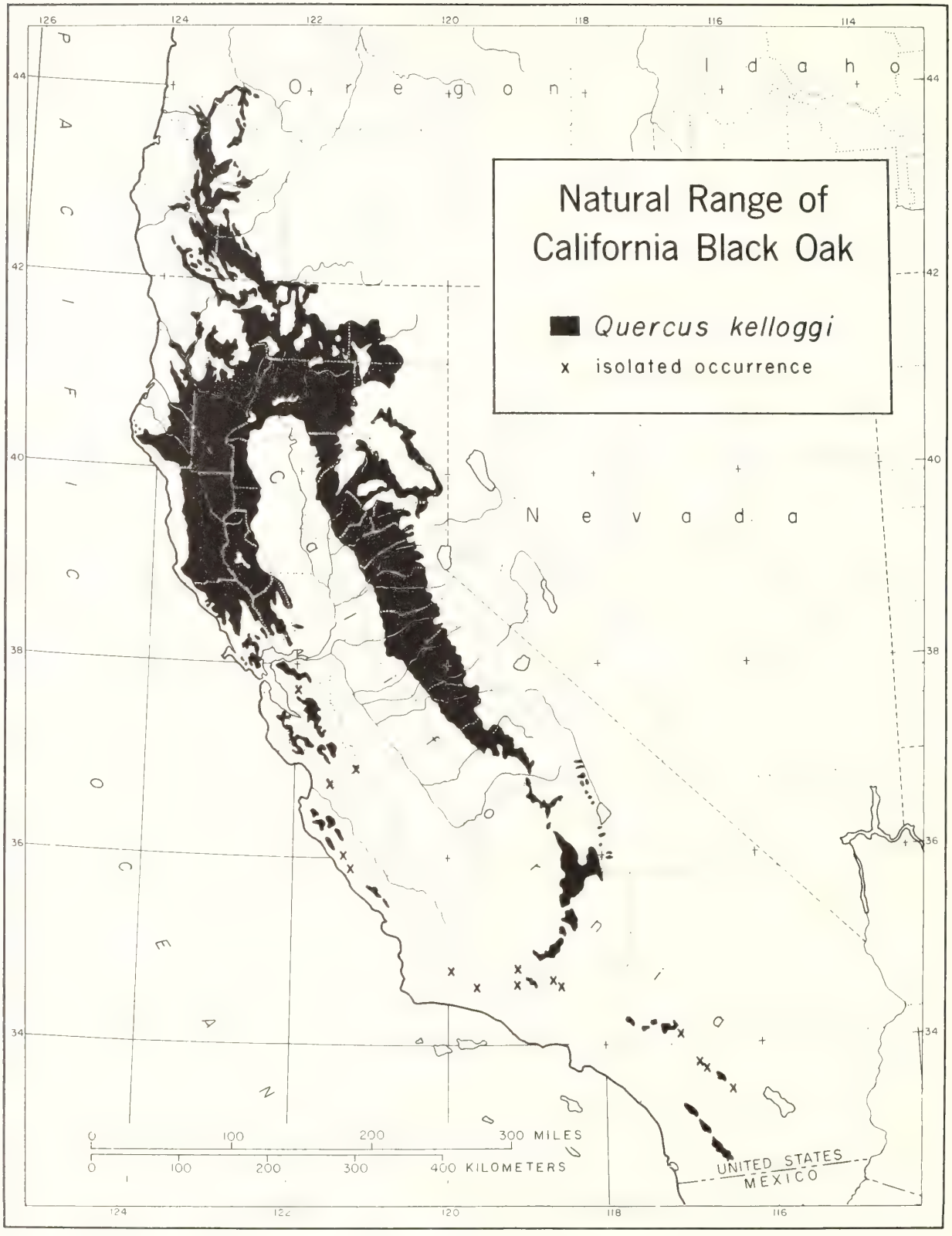

Figure 1.–*Natural range of California black oak.*

Edaphic

Probably the most important single soil variable that limits the occurrence of California black oak is internal drainage. Black oak is not found growing "with its feet wet." It is adapted to soils derived from diverse parent materials: andesite, basalt, granite, pumice, quartz diorite, sandstone, schist, shale, and volcanic tuffs and breccias. It is rarely found in serpentine soil. Occasionally it grows on soils derived from ultra-basic parent material, but mostly where above-average amounts of calcium seem to offset the deleterious effects of magnesium.

Soil textures favoring this oak range from medium textured loams and clay loams to the more coarse textured gravelly clay loams and sandy loams. Increasing clay content in the surface soil usually means a decreasing incidence of black oak. In fact, black oak rarely is found on soils with clay topsoils, particularly if the clay is of the heavy, sticky type. It commonly grows on thin soils and rocky slopes, but always at the cost of abundance or form, or both. In general, black oak grows best on the medium to coarse textured, deep, and well drained soils.

At least 75 soil series in California[2] and 14 in Oregon have been identified as supporting California black oak. Many of the important Oregon soil series are also present in California. Most of the important soils in California *(table 1)* support forest vegetation rather than oak-woodland or woodland-grass vegetation. The forest soils are mostly found at higher elevations where temperatures are cooler and precipitation is greater.

The best black oak stands in the Coast Range and Klamath Mountains are found on deep, slightly acid loams and gravelly clay loams derived from sandstone and shale. In the southern Cascade Range and northern Sierra Nevada, black oak grows best on deep loams and clay loams derived from metavolcanic rocks. In the central and southern Sierra Nevada and in the Transverse and Peninsular Ranges, black oak grows best on deep, acid to moderately acid sandy loam soils derived from granitic rock.

Like many deciduous hardwoods, black oak generally has a moderating influence on the pH of the surface soil. The large amount of organic material furnished annually to the forest floor may account for this influence. A 75 to 100-year-old black oak stand on the Sierra National Forest, California, contributed 1,380 pounds per acre of litter each year. Total organic matter above the mineral soil amounted to 39,100 pounds per acre (Jenny et al. 1949).

Physiographic

California black oak grows within a wide elevational range—from the level gravelly floors of low valleys to alluvial slopes, rocky ridges, and high plateaus. Most of the terrain is rough, steep, and strongly dissected by major streams and ephemeral drainages.

In Oregon, the elevational range of black oak varies from 450 feet near Eugene to over 1,000 feet on the low rounded hills in the Umpqua River drainage (Gratkowski 1961). It also occurs on the eastern slopes of the Coast Range and the western slopes of the Cascades within this elevational range. In south central Oregon and the Klamath Mountains, it grows at higher elevations (2,000-3,000 feet) (Whittaker 1960).

In California's Coast Range, black oak grows from about 500 feet along the Mattole River in Humboldt County to 6,000 feet in the Yolla Bolly Mountains. Black oak reaches its lowest elevation (200 feet) in the Napa and Santa Rosa valleys. Most black oak in the central portion of the Coast Range grows between 1,000 and 5,000 feet, gradually increasing in elevation but narrowing in range to 4,000-6,500 feet in Santa Barbara and eastern Ventura Counties. Farther south in the Transverse Range it is found at elevations of 4,600 to 7,000 feet (Horton 1960; Wright 1966). In the San Jacinto Mountains, it reaches 8,000 feet and at its southernmost extension in the Peninsular Range of San Diego County it grows within the 5,000-6,000 foot elevation.

The elevational range of black oak in California's Cascade Range is from about 600 feet in western Shasta County to 6,250 feet in south central Shasta County. In the Sierra Nevada, lower elevational limits for black oak range from 1,500 feet in the north to 4,000 feet in the south. Upper limits increase north to south from about 6,500 to 7,800 feet.

Black oak is most abundant and attains its largest size on the west-facing slopes of the southern Cascade Range and Sierra Nevada, from Shasta County southward through Tulare County, California *(fig. 2)*. Here it grows best on gently sloping benches, canyons, and draws with north and east aspects, although in deep canyons it grows equally well on nearly all aspects except southwest. Extensive stands of excellent development are also found in eastern Mendocino and Humboldt Counties of the north Coast Range.

[2]California soil series are identified by the California Cooperative Soil-Vegetation Survey and the National Cooperative Soil Survey. They are available from the Director, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, Calif. 94701.

Table 1.—*Principal California mountain ranges and soil series where black oak is found*

Mountain range	Sub-range	Range of counties	Soil Series
Coast	North Coast	Humboldt southward through Marin and Contra Costa	Boomer Cohasset Hugo Josephine Los Gatos Neuns Sheetiron Sites Tyson
Coast	Central Coast	Alameda southward through San Luis Obispo	Ben Lomond Boomer Felton Hugo Los Gatos Mindego Sheridon
Coast	Transverse and Peninsular	Santa Barbara southward through San Diego	Coarsegold Crouch Holland Shaver
Cascade	Southern	Siskiyou southward through part of Butte, Lassen, and Plumas	Aiken Cohasset Cone Forward Jiggs Letterbox Lyonsville McCarthy Nanny Shasta Sites Supan Tournquist Windy
Klamath	- -	Mainly Siskiyou, Trinity, and Shasta	Behemotosh Boomer Chawanakee Dubakella Horseshoe Hugo Josephine Kinkel Mariposa Marpa Neuns Sheetiron Sites Tatu
Sierra Nevada	Northern	Part of Lassen, Butte, and Plumas southward through Placer	Aiken Bonta Chawanakee Cohasset Fiddletown Haypress Holland Mariposa McCarthy Sites Tish Tang
Sierra Nevada	Central	El Dorado southward through Madera	Aiken Chaix Chawanakee Cohasset Fiddletown Crozier Hotaw Holland Horseshoe Mariposa McCarthy Musick Shaver Sites Stump Springs
Sierra Nevada	Southern	Fresno southward through Kern	Chawanakee Corbett Fiddletown Heitz Holland Musick Shaver Sheetiron Stump Springs

North and east aspects are most favorable in the central and southern parts of black oak's range, but it is found on just the opposite aspects in its northwesternmost locale. In Humboldt and northern Mendocino Counties, black oak grows on the warmer, drier south and southwest aspects.

The interaction of elevation and aspect often is of major importance. For example, at elevations below 1,000 feet bordering the Sacramento Valley in north central California, black oak occurs only in sheltered draws or on north slopes. With increasing elevation, favorable aspects increase until at 2,500 to 3,000 feet all aspects are generally favorable if soil depths are sufficient. Above 3,500 feet, north and east facing slopes are often devoid of black oak though other vegetation does well. In the southernmost mountains, black oak grows on the west-facing slopes, but only where deep soil, cool temperatures, and adequate moisture prevail.

Biotic

California black oak is a component of six forest types (Soc. Amer. Foresters 1954). It is the prime constituent of the California black oak type (No. 246) and important in two others: oak-madrone (No. 234) and Pacific ponderosa pine-Douglas-fir (No. 244). It becomes important in the ponderosa pine-sugar pine-fir (No. 243) and Pacific ponderosa pine (No. 245) types after severe disturbance or fire, and it is a minor component in the canyon live oak type (No. 249).

Figure 2.–*A mature black oak in the Shasta-Trinity National Forest, Shasta County, California.*

Cooper (1922) considered the oak-madrone forest a climax type "since it represents a degree of mesophytism between that of the chaparral and the conifer forest." Show[3] and others (Biswell et al. 1966; Horton 1960; Soc. Amer. Foresters 1954) noted that black oak and vegetative associates are especially prevalent after logging and wildfire, and implied that such stands were subclimax.

This oak or its progenitors were much more widespread in past ages than at present. The black oak-madrone forest began its development in the upper and middle Miocene as a result of increasing aridity (Mason 1947). Fossil flora in sedimentary deposits include an oak named *Quercus pseudo-lyrata* Lesq., which appears closely related to *Q. kelloggi*. *Q. pseudo-lyrata* has been found near Spokane and Ellensburg, Washington; in the John Day Valley and Blue Mountains of Oregon; and in northwestern Nevada. It was abundant at each location (Chaney 1925), even though each is far removed climatically from the present range of California black oak. Each of the 12 most common species in the fossil flora has an equivalent in the oak-madrone forest of today, and probable genetic lineages have been formulated for Miocene and modern species.

The most common botanical associate of black oak is ponderosa pine *(Pinus ponderosa* Laws.*)*. Wherever ponderosa pine grows, so can black oak. The two are nearly inseparable except that black oak grows on sites too poor to support pine and in certain areas within the redwood region of California where pine does not grow. Thus, in California and Oregon where the natural ranges of the two species coincide, ponderosa pine sites would be fertile ground for black oak. The converse is nearly always true.

Ponderosa pine is clearly the more aggressive species on the best sites. Above 3,000 feet in elevation, black oak often is crowded out by the thrifty pines or mixed conifers that spring up under it. It often serves as a nurse tree (Baker 1942; Barr 1946; Edwards 1957). The shade and leaf litter from black oak often ameliorate soil temperature and soil moisture during the growing season, so that dense clumps of pine, fir, and cedar develop vigorously beneath large-crowned trees while adjacent ground remains devoid of conifers (Barr 1946). At lower elevations, however, these effects decrease; at 2,500 feet pine seedlings grow well for a time but have difficulty growing through the oak, and below 2,000 feet, pines reach 3 to 4 feet in height but are weak and misshapen and in need of release (Baker 1942).

A rule of thumb is that black oak never grows through a stand of ponderosa pine, but can grow through brush (Edwards 1957). Black oak is eventually crowded out of the best sites and remains only as scattered remnants in dense mixed-conifer forests. There it often exists on "islands" of soil or terrain not favorable for conifers. An example in Tuolumne County, California, is on dry, rocky ridges with a western exposure at 5,800-6,400 feet (Stark 1965). Another, in Plumas County, is a fringe of black oak on dry rocky sites just above the mixed-conifer forest, at 4,500-5,500 feet.

Black oak grows either individually or in groves, some of which are quite extensive. Rarely does it exist as an understory. It usually is a component of hardwood stands or of mixed hardwood and conifer forests. Tanoak *(Lithocarpus densiflorus* (Hook. & Arn.) Rehd.*)* and Pacific madrone *(Arbutus menziesii* Pursh*)* are the most common hardwood associates of

[3]Show, S. B. Report to Supervisor, Shasta Forest Reserve. April 12, 1913.

black oak. Others are:

big leaf maple *(Acer macrophyllum* Pursh*)*
California buckeye *(Aesculus californica* (Spach) Nutt.*)*
Pacific dogwood *(Cornus nuttallii* Audubon*)*
California live oak *(Quercus agrifolia* Nee*)*
canyon live oak *(Q. chrysolepis* Liebm.*)*
blue oak *(Q. douglasii* Hook. & Arn.*)*
Engelmann oak *(Q. engelmannii* Greene*)*
Oregon white oak *(Q. garryana Dougl.)*
interior live oak *(Q. wislizenii* A. DC*)*
California laurel *(Umbellularia californica* (Hook. & Arn.) Nutt.*)*

Besides ponderosa pine, other conifer associates are:

white fir *(Abies concolor* (Gord. & Glend.) Lindl.*)*
grand fir *(A. grandis* (Dougl.) Lindl.*)*
western juniper *(Juniperus occidentalis* Hook.*)*
incense-cedar *(Libocedrus decurrens* Torr.*)*
knobcone pine *(Pinus attenuata* Lemm.*)*
Coulter pine *(P. coulteri* D. Don*)*
Jeffrey pine *(P. jeffreyi* Grev. & Balf.*)*
sugar pine *(P. lambertiana* Dougl.*)*
Monterey pine *(P. radiata* D. Don*)*
Digger pine *(P. sabiniana* Dougl.*)*
Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco*)*
bigcone Douglas-fir *(P. macrocarpa* (Vasey) Mayr.*)*
giant Sequoia *(Sequoia gigantea* (Lindl.) Decne.*)*
redwood *(S. sempervirens* (D. Don) Endl.*)*
California nutmeg *(Torreya californica* Torr.*)*

Shrub associates are numerous; the principal ones reported (Cooper 1922; McMinn 1951; Whittaker 1960;[4]) include 29 species *(table 2)*. In parts of Shasta and Trinity Counties, California, black oak itself takes a shrub form. There–sometimes growing alone, sometimes with other shrubs–dense, tangled stands develop. Nearly impenetrable by man, but preferred habitat for deer and upland game, such shrubby stands are generally strikingly uniform in height.

Except in these shrubby stands and at black oak's lowermost elevations, most shrubs generally are not competitive, nor particularly abundant over most of the forest land where black oak abides. After heavy cutting or fire, however, some of the more aggressive shrubs often compete strongly with black oak sprouts.

Table 2.–*Principal shrub associates of California black oak*

Scientific name	Common name
Amelanchier pallida Greene	western service berry
Arctostaphylos mariposa Dudley	Mariposa manzanita
A. patula Greene	greenleaf manzanita
A. pungens H.B.K.	Mexican manzanita
A. viscida Parry	whiteleaf manzanita
Castanopsis sempervirens (Kell.) Dudl.	bush chinkapin
Ceanothus cordulatus Kell.	mountain whitethorn
C. integerrimus H. & A.	deer brush
C. lemmonii Parry	Lemmons ceanothus
C. prostratus Benth.	squaw carpet
C. velutinus Dougl.	snowbrush
Cercis occidentalis Torr.	western redbud
Chamaebatia foliolosa Benth.	Sierra mountain misery
Garrya fremontii Torr.	Freemont silktassel
Holodiscus discolor (Pursh) Maxim.	ocean spray
Lithocarpus densiflora (H. & A.) Rehd. var. *echinoides* (R. Br.) Abrams	shrub tanoak
Photinia arbutifolia Lindl.	toyon
Prunus emarginata (Dougl.) Walp.	bitter cherry
P. subcordata Benth.	Sierra plum
P. virginiana L. var. *demissa* (Nutt.) Sarg.	western choke cherry
Purshia tridentata (Pursh) DC.	bitterbrush
Quercus garryana Dougl. var. *Breweri* (Engelm. in Wats.) Jeps.	Brewer oak
Q. vaccinifolia Kell.	huckleberry oak
Rhamnus purshiana DC.	cascara buckthorn
R. rubra Greene	Sierra coffeeberry
Rhus diversiloba T. & G.	poison-oak
Ribes roezlii Regel.	Sierra gooseberry
R. nevadense Kell.	mountain pink currant
Rosa californica C. & S.	California wild rose

When compared with 15 of its most common shrub associates in the Klamath Mountains of northern California, black oak ranked ninth in need of soil moisture, third in demands on soil, eighth in terms of tolerance, and first in rapidity of sprouting.[5]

Waring (1969) found black oak to weather severe transpirational stress quite well. In the northeastern Klamath Mountains of Oregon, it was able to withstand plant moisture stresses of 18-25 atmospheres–

[4]Show S. B. *Op. cit.*, footnote 3.

[5]Show, S. B. *Op. cit.*, footnote 3.

giving it 86-98 days within the normal growing season when soil moisture was not limiting. Few other plants were able to glean adequate moisture for this length of time. Thus presence of black oak signified sites where high moisture stresses were likely.

Numerous forbs and grasses are plentiful in the black oak range. They do not materially influence the growth of black oak in most situations.

LIFE HISTORY

Seeding Habits

Flowering and Fruiting

Flowering takes place from mid-March to mid-May—depending on elevation, physiography, and local conditions of climate. In general, trees near the coast and at lower elevations bloom earliest (Pelton 1962).

Flowers on black oak are unisexual. The plant is monecious. Staminate flowers are long (3.5 to 7.5 cm.) hairy aments that emerge from buds in the leaf axils of the previous year's growth *(fig. 3)*. The 5 to 9 stamens in each ament have bright red anthers and pale green filaments. The calyx is light green. Pistillate flowers are borne singly or 2 to 7 on a short stalk that originates from leaf axils of the current

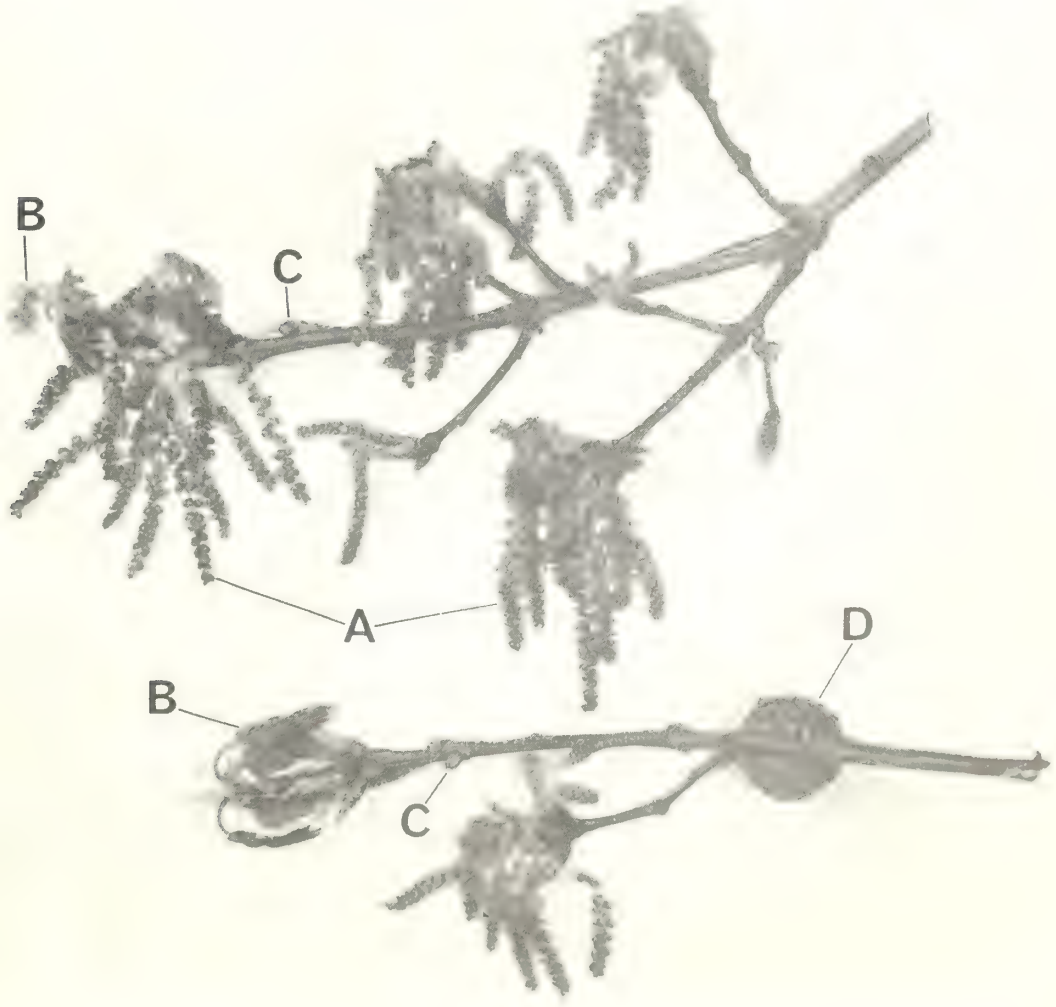

Figure 3.—*Flowering twigs.* A, *staminate flowers;* B, *just emerged leaves;* C, *immature acorns;* D, *cup of last year's acorn.*

year's growth. The stigmas are dark red (U.S. Forest Serv. 1948).

Acorns mature the second year. Early in the second summer the acorn is completely covered by the cup forming a globe-shaped knob about 1/4 inch in diameter (Jepson 1910). When mature, the light brown, thinly scaled cup encloses from 1/4 to 3/4 of the length of the acorn. The oblong (occasionally ellipsoid) acorns occur either singly or in clusters of two or three and vary widely in shape and size *(fig. 4)*. Sizes range from 3/4 to 1-3/4 inches long and from 3/8 to nearly 1-1/2 inches in diameter.

Seed Production

Abundant seed crops for entire stands are produced at 2- to 3-year intervals (Roy 1962; Sudworth 1908), but individual trees or groves of trees bear some seed nearly every year. In natural stands, black oak must be 30 years or older before it produces viable seed. It produces some seed sporadi-

Figure 4.–*Typical leaves, twig, and acorns of California black oak.*

cally between ages 30 and 75, but seldom large quantities before 80 to 100 years. Abundant acorn production continues at least to 200 years. In 1967, a year when the over-all acorn crop rated as fair, I estimated seed production on a single 150- to 200-year-old tree at 6,500 acorns.

The number of acorns per pound reported for black oak range between 16 (Wolf 1945) and 115 (U.S. Forest Serv. 1948). A pound of the largest size of acorn in figure 4 would contain 52 acorns.

Insects destroy many acorns—damage to nearly 60 percent of the annual crop has been reported in one locality.[6] Another pest is a species of cynipid *(Andricus* spp.*)* which heavily infests the acorns and forms galls in the kernels. Developing acorns are attacked by the filbert weevil *(Curculio uniformis* LeConte*)* and by larvae of the lepidopterous filbertworm *(Melissopus latiferreanus* Walsingham*)*. These two insects in some places infest up to 95 percent of the acorns and destroy most of a crop (Keen 1958).

Seed Dissemination

Mature acorns fall during September and October (Dixon 1934; U.S. Forest Serv. 1948), either just before or during leaf fall. Once they are on the ground, temperature can be critical. If the acorns are exposed, the often hot fall weather can cause severe drying. In August 1967, I found that mature acorns lying in light litter beneath felled trees had cotyledons withered to about half normal size 9 days after the felling. Acorns from the same trees but shaded by leaves and branches for about 3 weeks contained full sized cotyledons and germinated readily.

A blue-gray mold also damages fallen seed. I have examined undisturbed acorns about 2 months after leaf fall and some rain. The mold was visible in the circular scar formed by the absent cup, and had progressed well within the acorns. Jaeger (1920) reported that Indians would gather only freshly fallen acorns to avoid the mold.

Because the acorns are large and heavy, most of them fall directly beneath the tree crowns. Few bounce or roll very far on steep slopes covered by duff, leaves, and litter. Dissemination by animals is important—not so much because of the numbers of acorns moved, but because some of them are moved beyond the parent tree and enhance the spread of the species. The western gray squirrel *(Sciurus griseus)* and the scrub jay *(Aphelocoma coerulescens)* are the most important disseminators, for they bury the acorns, often after carrying them some distance from the seed source.

Acorns are eaten by at least 14 species of song and game birds, many species and subspecies of small mammals (mostly rodents), and mule and black-tailed deer (Martin et al. 1961; Jameson 1952).

Deer are prodigious consumers of acorns. They eat some in the fall and many in early and late winter, when bucks, does, and fawns root about in the fallen leaves and snow for them. Acorns are also avidly searched for in the spring, particularly in areas just exposed by melting snowbanks (Dixon 1934). On the Tehama winter deer range, where black oak makes up but 6 percent of the total vegetative cover, its leafage and acorns constituted 27.8 percent of the total monthly diet of mule deer in October and 21 percent in May (Leach and Hiehle 1957).

Black oak acorns form part of the diet of the band-tailed pigeon only in autumn, being 3.2 percent in September and 7.7 percent in November (Smith 1968).

Seedling Development

Germination and Establishment

California black oak can reproduce adequately from seed. For example, more than 45 black oak seedlings per square meter were found under a 26-inch tree.[7] At Challenge Experimental Forest and elsewhere in Yuba County, California, many black oak seedlings have become established on exposed mineral soil after logging and site preparation.

Nevertheless, seedlings are less important than sprouts in establishing stands. Seedlings extend the species into new areas; sprouts keep black oak in the same area and result in the establishment of many more stands than do seedlings.

Stands on new areas may become established from acorns disseminated by animals and birds. They are also established by seedlings that spring up under isolated trees and nearby conifers. If the overstory is then burned, broken, or destroyed the oak seedlings become free to grow. Even if seedlings are damaged during removal of the overstory, they promptly sprout. These sprouts prosper and form new black oak stands.

Natural seedbed requirements for germination are not rigid. Either undisturbed leaf litter or, to a lesser extent, moist, well aerated mineral soil are good seedbeds. Establishment is almost nonexistent on

[6] Radtke, L. B. Forest insect conditions on the Hoopa Indian Reservation. 1939. (Typewritten.)

[7] Personal correspondence with Dale O. Hall. U.S. Forest Service, February 14, 1966.

heavy clay soils or soils compacted by logging machinery, because the new radicle cannot penetrate the soil far enough and fast enough to avoid searing soil surface temperatures.

Germination occurs in the spring when warm weather begins. It probably is regulated by light, temperature, moisture, and depth of soil or litter. Thus germination, both in magnitude and timing, is highly variable. Germination is hypogeous; that is, the acorn remains below ground. The radicle is first to emerge and grows downward for some time, often 10 to 15 days, before the hypocotyl appears above ground. This process benefits the seedling both in getting to and staying in available soil moisture, and in minimizing transpirational losses. Sometimes a single acorn may put forth several hypocotyls, particularly if upward progress is hampered by a stony or crusty soil. Burying the acorn 3 to 4 inches deep also leads to several hypocotyls. Genetic character seems to govern the number of above-ground stems, too, because acorns from one parent tree will result in more multi-stemmed progeny than those from another, other factors being constant.

Under optimum conditions, about 15 days elapse between sowing and the beginning of germination (Mirov and Kraebel 1937). In nature, the germination period can be several weeks. Germinative capacity is highly variable and changes with the degree of insect infestation and amount of mold, among other factors. Germination has been reported as high—95 percent—(Mirov and Kraebel 1937) and as scanty (Sudworth 1908). In a 1966 test by the Pacific Southwest Station, total germination was 32 percent with sound acorns sown in fall and allowed to over-winter; 30 percent germinated in 91 days.

Before germination can begin, the seed requires a period of after-ripening to overcome dormancy. Over-wintering in the forest floor normally breaks dormancy under natural conditions. Stratification in moist peat or leaf mold for 30 to 45 days at 32° to 45°F. is recommended for artificial regeneration (U.S. Forest Serv. 1948).

Acorns can be stored in sacks in a cool room for 1 to 2 months if they are not allowed to overheat or dry out (Mirov and Kraebel 1937). Mold is often a problem, and control measures need to be applied before storage. In general, little is known about storage criteria and conditions, or even if storage is possible for periods exceeding 6 months. The classical storage criteria of a low moisture content and a just-below-freezing temperature are fatal to black oak acorns. They must be stored at a high moisture content which precludes storage at temperatures below freezing. Under these conditions, the acorns sprout; hence some means of inhibiting sprouting may be the key to long-term storage.

Early Growth

Black oak seedlings often reach a height of 2 to 4 inches and a taproot length of 9 inches in the first 28 days of growth. During the first growing season, seedlings only 4 to 6 inches tall may extend their taproots as deep as 30 inches. Lateral root development is slow—the longest lateral on a 30-inch taproot being only 1 inch. The fast growing vertical root makes black oak seedlings well adapted to cope with the hot dry summers characteristic of their range.

Soil moisture is seldom a limiting factor during early growth, and seedlings become established in dense shade beneath trees and shrubs or in full sunlight. In dense shade, seedlings grow spindly and may be only 10 to 12 inches high when 10 years old. The spindly stems often topple over, remain prone for a distance of a foot or more, and then turn upward again. With removal of the overstory, the spindly stems sunscald back to the root collar and resprout, usually with a single stem. Annual growth rates for seedlings are probably slow to moderate for the first few years and better in full sunlight than under partial shade.

Damage to young seedlings by late spring frosts normally is minimal. When damage does occur, the seedlings may sprout from below ground.

Vegetative Development

Black oak sprouts profusely after cutting or fire. Most sprouts develop from latent buds which lie under the bark at, or slightly above, the root collar. But a tree must be damaged extensively before sprouts from the root collar appear. Oak boles often "feather" profusely after defoliation or severe breakage without a single sprout from below ground. Removal of bark from up to three-fourths of the basal circumference of a tree often induces sprouting on the bole, but not beneath the groundline.

Sprouts may also appear from the top of the stump (stool sprouts) or occasionally from lateral roots near the soil surface. Stool sprouts are undesirable for two reasons: they are weakly attached to the parent stump, and they are prone to heart rot at an early age (Edwards 1957). Fortunately, stool sprouts are scarce. When present they almost always are growing on an abnormally high stump (higher than 18 inches), a very large stump (old tree), or on stumps so surrounded by logging debris that only the cut surface is exposed.

The size and vigor of the parent tree determine the number of sprouts and their height and crown spread. In general, stumps from larger trees produce both a larger number of sprouts and more vigorous ones *(table 3).* Only very old, moribund trees fail to produce any sprouts after cutting.

In nearly all sizes of trees, low stumps produce many more sprouts than high stumps. High-stumping older, larger trees result in undesirable stool sprouts, and often no sprouts from below ground.

Sprouts grow vigorously *(table 4).* Although deer browse the sprouts to some degree each year throughout most of the range of black oak, the rapid early growth of sprouts can put them beyond the reach of deer in two growing seasons. Occasionally browsing is fatal. In Mendocino County, for example, a deer population of 1 per 6 acres practically eliminated oak over large areas of the Coast Range.[8]

Sunscald and breakage also damage young sprouts. Normally, only the outermost sprout stems are affected by sunscald. Breakage occurs because of the surprisingly weak connection of the sprouts to the root collar. The slightest side pressure often is enough to break off a sprout. For this reason, thinning of first-year sprouts is impractical.

Because of rapid height growth, young sprouts outdistance other vegetation, including coniferous associates, allowing black oak to be dominant for many years. After the living crown has moved

[8]Personal correspondence with William M. Longhurst, Zoologist, Hopland Field Station, Univ. Calif. March 8, 1966.

Table 3.—*Sprout development in California black oak relative to size and vigor of parent stump, Yuba County, California, 1968*[1]

Stump		4-year-old sprouts		
Diameter class (inches)	Diameter growth of last 10 rings	Average number of sprouts per clump	Mean height of 3 tallest sprouts per clump	Mean crown diameter of sprout clumps
	Inches		*Feet*	*Feet*
< – 8.0	0.44	17	7.1	3.5
8.1 – 12.0	.73	28	7.8	4.6
12.1 – 16.0	.64	42	7.8	5.0
16.1 – 20.0	1.70	43	8.4	4.9

[1]Basis: 29 (52- to 55-year-old) parent stumps; high site, overstory completely removed.

Table 4.—*Sprout development of California black oak following cutting, Yuba County California, 1968*[1]

Time after cutting (years)	Sprouts per clump	Mean height of three tallest sprouts per clump	Crown diameter of sprout clump
	Number	*Feet*	*Feet*
1	--	2.2	1.9
2	33	4.9	3.9
3	32	7.1	4.0
4	31	7.9	4.7

[1]High site, overstory completely removed, no browsing or injury.

considerably up the bole, black oak then begins its role as a nurse tree, allowing conifers to progress toward equal or dominant positions in the stand. The vigorous, abundant sprouting of black oak after logging or fire helps reduce soil erosion and protects valuable watersheds as well.

Propagation by layering, rooting of cuttings, or grafting has not been reported. But the wartime shortage of cork in the 1940's stimulated the grafting of cork oak *(Quercus suber* L.*)* onto black oak stocks. In a greenhouse trial, 70 percent of the grafts were successful (Mirov and Cumming 1945).

Sapling Stage to Maturity

Rooting Habits

Various investigators have described the rooting system of black oak as having no taproot but large spreading roots,[9] as deep and long lived (Van Dersal 1938), and with a strong taproot (Jepson 1910). Differences in age and soil probably account for these conflicting reports. Trees which start with a taproot system may develop a spreading root system later, particularly in heavy soils. An early observer reported black oak to have "strong laterals, more or less deep, depending on depth to ground water level."[10] A recent study, in Placer County, California, using radioactive water, suggested that black oak roots draw water from an 80-foot depth in fractured and jointed metamorphic rock (Lewis and Burgy 1964).

Observations of road cuts indicate that soil depth is important to rooting habit. In shallow soils, one to several vertical roots usually penetrate to rock, then become lateral and spread out to great lengths directly on top of it. At fissures, "sinker" roots penetrate the rock itself. Where the shrub form of black oak grows, a great profusion of roots become established at the soil-rock interface, and root grafting is common. Roots from one clone often overlap those from another and interclonal root grafting occurs. In such situations, the soil is fully– perhaps too fully–occupied by the black oak root systems. In deeper soils, one to several roots will grow downward almost vertically. Thus on the better soils black oak trees can have a single taproot, but a root system consisting of several deep-growing vertical roots is more likely. In any case, black oak is notably windfirm.

[9]Lyons, George W. File Report, Silvical Leaflet; Black Oak. U.S. Forest Serv. 7 p. Typewritten, January 13, 1912.

[10]Berry, Jason B. File Report, Silvical Leaflet; California Black Oak. U.S.Forest Serv., Inyo Nat. Forest. 5 p. Typewritten, Aug. 10, 1911.

Reaction to Competition

Black oak is regarded as intolerant throughout most of its life (Edwards 1957), but its reaction to shade varies with age. It is moderately tolerant in early life, growing well in full sunlight but persisting in dense shade (Roy 1962). As a sapling and small pole, it is less tolerant and often becomes long and skinny in reaching for a position in the canopy where it can receive overhead light. Should it be overtopped, the tree either dies outright or dies back for 1/3 to 3/4 the total bole length, and the living remainder produces a few short epicormic branches. These branches may keep the tree alive for some time, but continued overtopping results in death.

The need for top light increases as the tree ages. In fact, the species is noticeably phototropic. On south-facing aspects, trees grow nearly perpendicular to the slope–straight at the sun. In dense stands, black oak often fills a "hole" in the canopy even though it has to lean 15- to 20- degrees to do so. In both cases, the "leaning" stems are perfectly straight and without the J-shape normally found in other species under similar conditions.

Most black oak stand tables show that the percentage of large diameter trees increases with age (Biswell et al. 1966). With time, smaller trees become fewer and fewer, and no new ones replace them. This lack of small trees in the understory suggests intolerance.

Growth

Nearly all black oaks that I have seen were of sprout origin, and there is much evidence that most black oak stands originate from sprouts (Edwards 1957). The remainder of this section, therefore, deals with the growth and yield of sprout stands.

Number of sprouts per clump influences growth, form, and, eventually, yield. The number per clump decreases rapidly with age; by the time the trees are pole-size, individual clumps contain 1 to 3, or occasionally 4, stems *(fig. 5).* In general, sprout persistence is greater on the poorer sites, and more stems per clump will be living at a given age than on better sites.

The form of California black oak varies greatly. On the fringe of its range and on marginal sites it assumes the shrub form. In close stands on good sites, it is tall and straight with a clear bole and thin crown. When open grown, it is prone to fork repeatedly, becoming multi-stemmed and broad crowned *(fig. 6).*

In Shasta County, California, all of these forms can often be found on the same slope and exposure: the brush form at the top of the slope, a stunted, gnarled form further down, and tall, straight trees

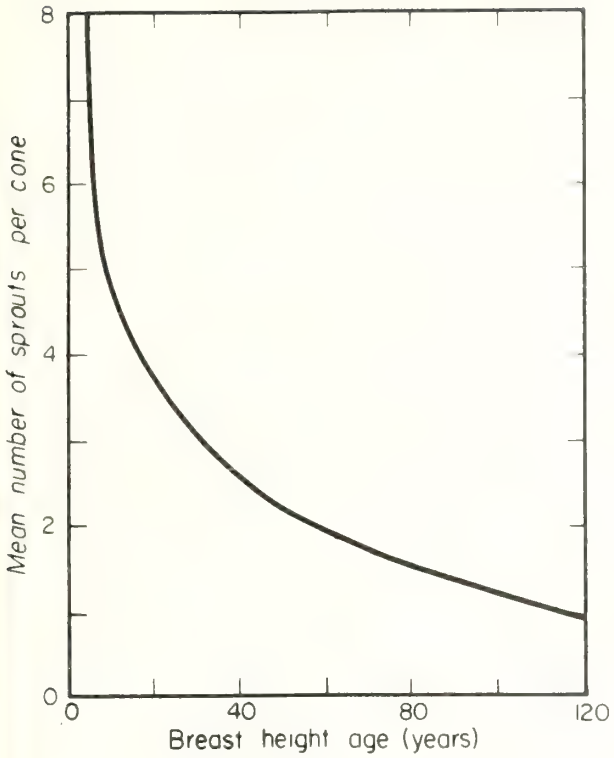

Figure 5.–*Number of sprouts by age of California black oak. Basis: 180 clones, many California sites.*

even lower. Tree form often is especially good on the toe of slopes or gently sloping benches.

Site index often increases rapidly with distance downslope, being best on relatively level benches which have deeper soils and better moisture regimes. Average site index at 50 years is about 50 feet; better-than-average, about 60 feet; and on poor sites only 35 to 40 feet *(fig. 7)*. Height and age relationships are consistent on all aspects through age 40. After age 40, ranking by aspect from best to worst is: east, closely followed by north and west, with south lagging far behind *(fig. 8)*.

Throughout the first 40 years of an average tree's life, it grows about 1.2 feet per year in height. The growth rate then tapers off; by age 70 the cumulative rate has decreased to 0.9 feet per year. At 100 years, the over-all growth rate will be about 0.75 feet per year.

Diameter growth tends to be slow during the first 25 years of life. Competition for position in the canopy tends to favor height growth at the expense of diameter growth. At 25 years, the average tree is nearly 35 feet tall, about 4 inches in diameter, and is one of three sprouts in the clump. From age 25 to 65, black oak puts on its best increase in diameter *(table 5)*. Its growth can reach 3 rings per inch (Edwards 1957). At age 65 the tree is about 11.5 inches d.b.h. and has grown at nearly 0.2 inches per year.

Black oak in an understocked stand averages 13 to 14 inches in diameter at 65 years; in an overstocked stand, between 7 and 9 inches. After age 65, diameter growth slowly declines. By age 90 most trees are mature.

Black oak may live to be nearly 500 years old,[11] but age–diameter relationships beyond 120 years are uncertain. Trees 20 inches in diameter can range between 70 and 175 years. Sudworth (1908) reported that trees 16 to 25 inches d.b.h. were 175 to 275 years old. Trees over 40 inches d.b.h. have been noted as being 200 to 325 years old.

In contrast to these data from natural, unmanaged stands, diameter growth rates of 3 to 6 rings per inch can be expected in plantations. The height-age relationship for natural stands should hold in plantations, at least for close spacings.

[11] Lyon, George W. *Op. cit.*, footnote 9.

Figure 6.–*An open grown black oak in Yosemite National Park, California.*

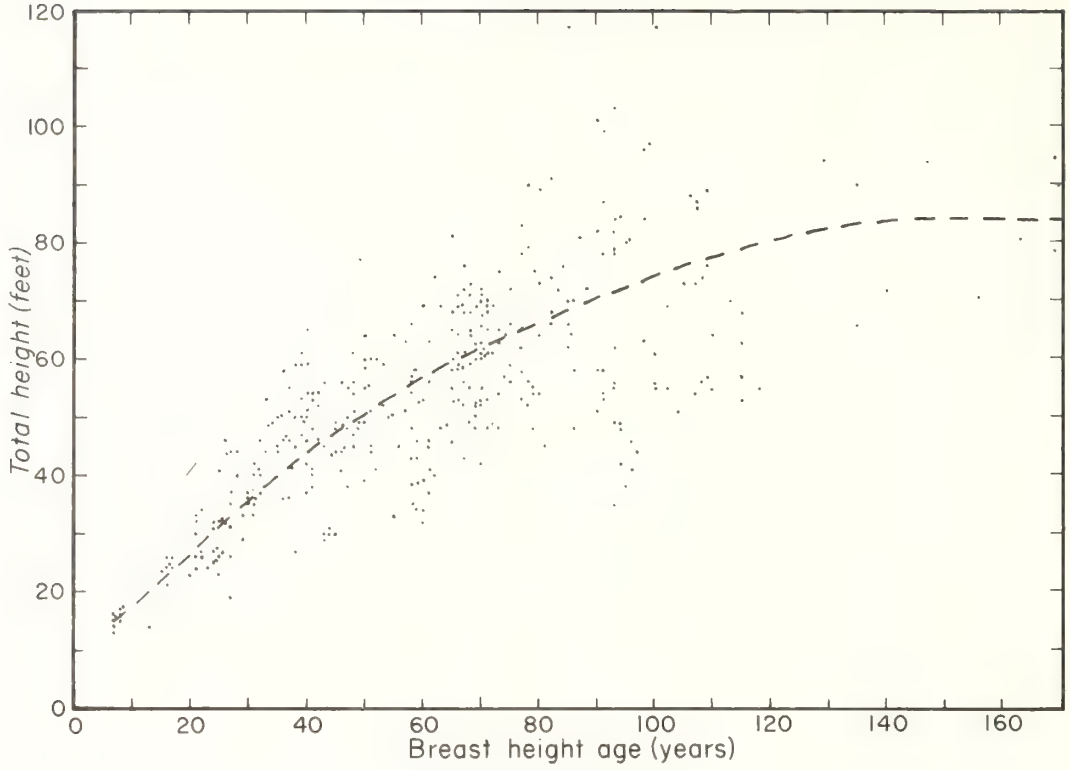

Figure 7.–*Height and age of dominant California black oak in natural stands. Basis: 393 trees, statewide California.*

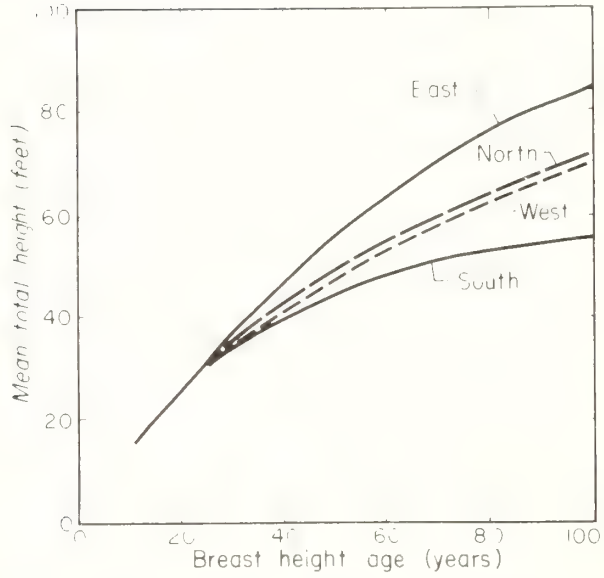

Figure 8.–*Height and age by aspect, California black oak. Basis: 393 trees, statewide California.*

Table 5.–*Diameter growth in natural stands, California black oak, 1968*[1]

Age (years)	D.b.h.	Average cumulative increment per decade	Single bark thickness	Rings per inch
	Inches	*Inches*	*Inches*	*Number*
20	3.4	1.70	0.17	13.1
30	5.4	1.80	.27	12.4
40	7.2	1.80	.37	12.4
50	9.0	1.80	.46	12.4
60	10.8	1.80	.55	12.4
70	12.2	1.74	.62	12.8
80	13.4	1.68	.68	13.2
90	14.6	1.62	.74	13.7
100	15.6	1.56	.80	14.3
110	16.6	1.51	.85	14.8
120	17.5	1.46	.89	15.3

[1]Basis: 405 dominant trees in 45 even-aged stands, many California sites.

Black oak seldom exceeds 5 feet in diameter or 130 feet in height. The largest black oak tree recorded has a circumference of 36 feet and grows in Yosemite National Park (Dixon 1961).

In terms of crown and bole weight, black oak is intermediate between Pacific madrone and tanoak (Sundahl 1966). Crown and bole weights (oven dry basis) for black oak are:

Diameter (inches):	*Age* (years)	*Crown weight* (pounds)	*Bole weight* (pounds)
6	35	60	90
10	55	130	320
14	85	200	800
18	120	300	1,700
24	--	550	3,450

Black oaks are capable of large and rapid increases in diameter growth when freed from overstory. On a high site in Yuba County, California, several trees of good form were increment-bored 4 years after logging and site preparation. Before logging, the oaks were at least partially overtopped by large conifers. After logging they were dominant. In the first growing season after cutting, the average diameter increment increased 270 percent over the previous year. The greatest increase was 340 percent. Release was relatively uniform within the tested diameter range of 5 to 16 inches. Four years after cutting, the growth rate was 27 percent greater than that for the first year after cutting.

Yield

The sawtimber volume of merchantable California black oak has been estimated at well over 1 billion board feet in California,[12] with nearly 1.3 billion board feet claimed to be in Oregon (Metcalf 1965). Most of it is probably in trees less than 20 inches in diameter. Growing stock volumes are substantial. Because most existing stands resulted from logging and fire shortly after 1900, most of the growing stock is fast approaching the merchantability threshold.

An "average" stand *(fig. 9)* has 440 trees per acre 3.5 inches in diameter and larger at breast height, and would yield slightly over 65 cords per acre.

Principal Enemies

Fire.—Fire is black oak's worst enemy. Crown fires kill trees of all ages and ground fires often are fatal. Only a little heat causes long vertical wounds to the trunk. "A gentle lick of flame up the trunk can cause severe scorching" (Edwards 1957). At first glance the tree may appear unhurt, but the cambium is dead. Bark thickness on mature trees varies from 0.75 to 2 inches, but even the thickest bark does not provide good insulation from fire. Scars resulting from scorching often become a point of entry for fungi. On larger trees, repeated fires enlarge old scars, reducing the bole to a shell or actually toppling the tree.

Disease.—California black oak is especially susceptible to fungi. Heart rot of the bole and larger limbs of living trees, caused mainly by two pathogens, *Polyporus dryophilus* Berk. and *P. sulphureus* (Bull.) Fr. *(fig. 10)*, is the principal damage (Meinecke 1914). These rots enter the tree through broken branches or open wounds created by fire or logging. Both fungi can, and often do, reduce the bole and large limbs of older, decadent trees to mere shells (Hedgecock and Long 1914). Younger trees also can have heart rot. Infection probably bridges from rotting stump to young sprouts, particularly to stool sprouts. By the time a natural black oak stand is 85 years old, heart rot has become serious, *(fig. 11)* and some stands fall apart as the disease-weakened limbs and boles are broken by wind and snow.

The hedgehog fungus *(Hydnum erinaceus* Fr.*)* also is found in the heartwood of living trees and *Polyporus adustus* (Willd.) Fr. in the sapwood, though neither are prevalent.

Another serious pathogen, *Armillaria mellea* (Vahl.) Quel. causes decay of the roots and butt of older decadent black oak. Sometimes it so weakens the root system that the tree topples over on a perfectly calm, still day; consequently *A. mellea* is a tree hazard to watch for in high-use recreation areas (Wagener 1963). This pathogen is indigenous in black oak, but younger vigorous trees do not seem to be affected by it.

Three other fungi—*Polyporus versicolor* L. ex Fr., *Stereum hirsutum* (Willd.) Fr., and *Schizophyllum commune* Fr.—are often seen on dead sapwood of living trees or on hardwood slash, but are of minor silvicultural significance.

California black oak is prone to several leaf diseases, chiefly the oak leaf fungus *(Septoria quercicola* Sacc.*)*. Other leaf diseases are the oak anthracnose *(Gnomonia veneta* (Sacc. & Speg.) Kelb.*)* (U.S. Forest Serv. 1958), powdery mildews *(Microsphaeria* and *Sphaerotheca* spp.*)*, a leaf blister fungus *(Taphrina coerulescens* (Desm.) Tulasne*)*, and a leaf rust *(Cronartium* spp.*)*.[13] Black oak usually survives

[12]Personal correspondence with Daniel D. Oswald. U.S. Forest Service. June 23, 1966.

[13]Personal correspondence with Willis W. Wagener. U.S. Forest Service. April 11, 1966.

Figure 9.–*Interior view of a natural 70-year-old California black oak stand of average stocking, density, and growth rate. Trees average 12 inches in diameter and 60 feet in height.*

Figure 10.–*Fruiting bodies of the sulfur fungus (Polyporus sulphureus) on a living California black oak, Yuba County, California, 1967.*

repeated defoliations, but growth loss and a lowering of vigor can be expected (U.S. Forest Serv. 1958).

True mistletoe (probably *Phoradendron flavescens* (Pursh) Nutt. var. *villosum* (Nutt.) Engelm. in Rothr.) often is seen on open-growing black oak *(fig. 12)* or in the uppermost crowns of trees growing close together. Damage consists of an undetermined loss of growth increment but the over-all effect probably is minor.

Climatic fluctuations also cause injury. For example, black oak leaves were extensively damaged by high temperatures immediately following cool, rainy weather. This damage covered an extensive area of northern California in 1941 (Mielke and Kimmey 1942). In February 1968, unusually wet, heavy snows caused severe crown and bole breakage in black oak at elevations of 2,300 to 2,800 feet in the northern Sierra Nevada.

Large swellings often are found on the bole and branches of black oak *(fig. 13)*, but little is known of their origin or morphology. Wounding or some unusual growth stimulus are two possible causes of this phenomenon. Surprisingly, no undue tendency

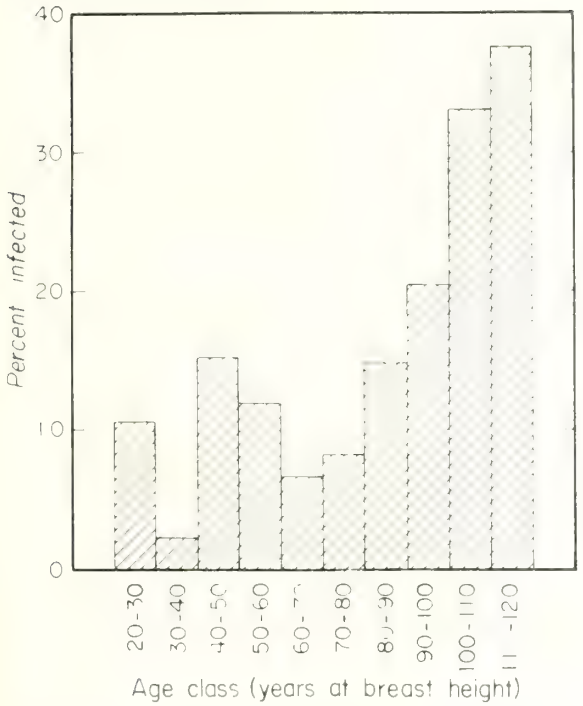

Figure 11.–*Incidence of heart rot at breast height in 375 sound-appearing dominant black oaks, many California sites. (Percentages shown are minimal because obviously decayed trees were not included. Only incipient rot was found in the sample trees. Growth rings were clearly visible in all cases.)*

for breakage is associated with these swellings either on living or standing-dead trees.

Animals.–Black oak foliage is browsed during all seasons, but especially in spring when new growth is tender (Robinson 1937) and in winter when twigs are eaten (Leopold et al. 1951). Deer eat reproduction, sprouts, and low foliage. Even in midsummer, newly germinated seedlings with acorns attached are often consumed by deer (Dixon 1934). Cattle also browse black oak (U.S. Forest Serv. 1937), but their numbers are declining.

Insects.–Many insects derive their sustenance from black oak. The damage is usually secondary, reducing growth but seldom killing the tree. Among sucking insects, the pit scales *(Asterolecanium minus* Lindinger and *A. quercicola* Bouche*)* have the greatest potential for damage (Brown and Eads 1965; Pritchard and Beer 1950). But the most destructive insect probably is the carpenter worm *(Prionoxystus robiniae* Peck*)*. Larvae of this insect mine the sapwood and heartwood of trunk and limbs and cause injuries that appear later as defects in lumber (Keen 1952).

Other insects are capable of heavy damage, especially when infestations become epidemic. The oak twig girdler *(Agrilus angelicus* Horn*)* is the most important insect affecting oak in southern California during drought years (Brown and Eads 1965). Sometimes oak bark beetles *(Pseudopityophthorus* spp.*)* attack and kill weakened trees, but normally, damage is confined to injured, felled, or recently killed trees (Keen 1952).

Defoliators also can damage black oaks. The California oakworm *(Phryganidia californica* Packard*)* is noted for defoliating trees in northern California. In 1968, the fruit-tree leaf roller *(Archips argyrospilus* Walker*)* caused apparently heavy damage over a wide area in the Sacramento River drainage in northern California. Many trees were left virtually leafless, but by mid-July evidence of the attack could scarcely be found.

Figure 12.–*Tufts of true mistletoe. This sun-loving, virtually enemy-free pest, infests a California black oak overlooking an arm of Shasta Lake.*

Figure 13.—*A large swelling (probably a noninfectious gall) on an otherwise healthy black oak, Yuba County, California.*

RACES AND HYBRIDS

Two natural hybrids are recognized: *Quercus* x *ganderi* C. B. Wolf *(Q. agrifolia* x *Q. kelloggii)* and *Quercus* x *morehus* Kellogg *(Q. kelloggii* x *Q. wislizenii)* (Munz 1959). Another hybrid, *Quercus* x *chasei* McMinn, Babcock, and Righter *(Q. agrifolia* x *Q. kelloggii)* has been described in Monterey and Santa Clara Counties (Munz 1959).

Of the hybrids, *Q. morehus* is by far the most widespread, ranging throughout California and even found, though rarely, in south central Oregon (Little 1953). The tree is distinguished readily in the winter by its rather sparse evergreen foliage in contrast to the completely deciduous black oak. New leaves in spring form a dense mass of shiny green foliage on the hybrid.

No varieties of black oak are reported, but one form—*cibata* Jepson—is described as a low or semi-prostrate shrub (McMinn 1951). It grows primarily in Shasta County and along the easternmost edge of Trinity County, California. It may occur in Tehama and Tulare Counties.[14] This form is generally found at elevations from 3,000 to 6,500 feet. Between 2,000 and 3,000 feet, it grows in mixture with the shrubby Brewer oak, gradually grading to pure Brewer oak below 2,000 feet. The soils on which the shrub form grows are almost always exposed, shallow, droughty, and often unstable, being chiefly old slides, talus slopes, and colluvial material. Slopes are often steep (70 to 80 percent). The roots fully occupy all available soil, and the great profusion of stems normally forms extremely dense stands. Increment borings from these shrubs have shown the over-all growth rate to be slow and 5 times as rapid the first 2 to 6 years as in the remaining 31 to 46 years. The shrubs average 4 to 8 feet in height and about 3 inches in diameter 1 foot above the ground.

Although described as a true shrub form, there is a question about its status as a botanical form. No criteria are known for distinguishing between it and the scrawny, scrub black oak tree.

SPECIAL FEATURES

The forks of open grown black oak were put to good use in the 1870-1880's in Mendocino County, California. Those of specific dimensions were used as "naturally assembled" ship keels and ribs.

Black oak leaves were said to be highest of the California oaks in food value for fattening cattle (Mackie 1903). And the acorns, high in edible oils, are a potential source of thousands of tons of human food (Wolf 1945). California Indians shelled and ground acorns into a flour or meal, leached it to

[14]Personal correspondence with James I. Mallory. U.S. Forest Service. September 14, 1968.

remove the bitter taste, and made soup, bread, and a form of pudding. Sometimes the meal was leached through cedar twigs for flavor. Occasionally it was allowed to accumulate mold. This mold was scraped off, kept in a damp place, and used to heal boils and sores (Sweet 1962).

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DEPARTMENT OF AGRICULTURE
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INFORMAP...

a computerized information system for fire planning and fire control

Theodore G. Storey Ross D. Carder Ernest T. Tolin

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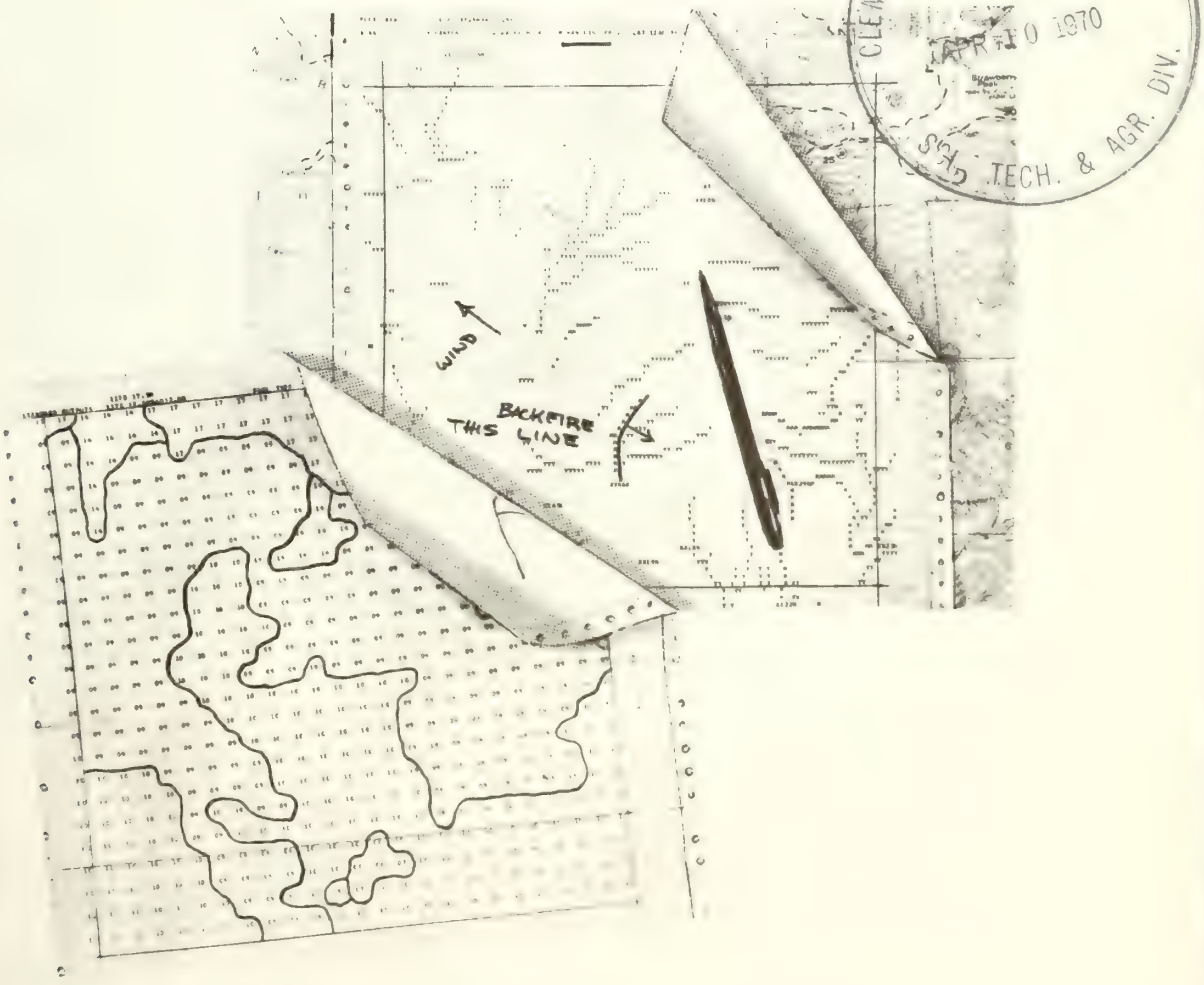

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The Authors

THEODORE G. STOREY and **ERNEST T. TOLIN** are assigned to the Station's Forest Fire Laboratory, Riverside, Calif. Theodore G. Storey is a 1948 forestry graduate of the University of California, Berkeley. He joined the Forest Service in 1949. Besides service with the Pacific Southwest Station, he has worked at the Southeastern Station, including its Forest Fire Laboratory, at Macon, Georgia. He is now doing research in fire management systems. Ernest Tolin is a computer programer with the Station's fuel-break research staff. **D. ROSS CARDER**, an industrial engineer, holds a bachelor's degree in mathematics (1965) from the University of California, Los Angeles. He joined the fire management systems research staff, at Riverside, Calif., in 1966. In 1968, he transferred to the Forest Service's California Regional Office, San Francisco, where he is working on analyses of transportation systems.

Procedures for processing data in fire planning and fire control have not changed significantly since the early 1930's, when the present methods were developed (U.S. Forest Service 1959, 1963, 1968). Data from maps, charts, and lists are still gathered, analyzed, updated, summarized, and displayed by using slow laborious hand methods. This traditional technique in planning before fire occurs limits the number of variables that can be included. And because it is slow, some information becomes quickly outdated, certain variables pertinent to the analysis cannot be included, and all possible alternatives cannot be explored. The shortcomings of current methods can be crucial in fire control manning—planned equipment-levels may be insufficient to suppress the fire, or unneeded forces may be assigned.

Traditional data-handling methods can stall the most effective control action during going fires. Manual techniques are used to dispatch crews, to delineate and update status and strategy maps, to inventory men and equipment, to allocate forces, and to assess and predict fire weather and fire behavior. But in many cases these are too slow to cope with the rapidly changing conditions—sometimes from minute to minute—in a raging fire. Unless the fire boss has up-to-the-minute data, he cannot make the soundest decisions. Needless acres may be burned and damage incurred. Human life could be jeopardized.

Instead of manual methods of data processing, the obvious alternative is machine or automated methods. New and more sophisticated fire planning and fire control systems now under development are based on computer techniques and will require compatible data for both the research and the operational phases. The volume of data needed and their complexity will be greater than that in traditional systems.

We have developed the basic framework of a computerized information system called INFORMAP, or *Information Necessary For Optimum Resource Management and Protection.* The first phase in developing this system has been completed. It consisted of work in (a) identifying the major items of data needed and the data handling requirements of fire planning and fire control, (b) designing a coding system to enter data manually for computer storage, and (c) developing and testing some of the computer programs for retrieving and updating stored data, for combining data, and for displaying results *(fig. 1).*

To test INFORMAP, we used data from a representative 50-square-mile area on the San Bernardino National Forest, in southern California, and a 60-square-mile area on the Coronado National Forest, in Arizona.

INFORMAP uses punchcards to enter, manipulate, update, and retrieve data. Storage is on magnetic tapes. A high-speed line printer in close proximity to the computer produces 12-inch square printouts. The computer program is written in Fortran IV for the IBM 7040 computer. This batch processing operation in which the computer handles one job at a time, has proved fast enough for the fire planning application of INFORMAP, but too slow for the fire control.

This paper compares INFORMAP with other information assembly and display systems, describes the concept and basic characteristics of the system, explains how it may be used in fire planning and fire control, and considers the outlook for its future development.

INFORMATION ASSEMBLY AND DISPLAY SYSTEMS

Computerized information assembly and display systems fall into two broad classes: planning systems and tactical systems. The distinction between the two is, however, not clear cut, although tactical systems generally are more complex, require greater over-all speed of operation, and more interaction between the man and the computer. A computer is usually the heart of both a planning and a tactical system. Peripheral equipment may include line printers, plotters, listers, microfilm readers, and slide projectors for handling and displaying data.

Tactical systems must enable the decision-maker or operator, who is usually at a remote location, to ask a question or make a request of the system and receive a quick reply, i.e., to converse with the computer. The information received must be current and it must be displayed in a convenient form so that the decision maker can assimilate it as rapidly as possible. Portions of the system must be "real time," with the ability in forest fire applications for example, to compute predicted fire perimeter from data acquired by sensors or by other rapid means before the actual perimeter has changed appreciably. These requirements generally make tactical systems much more expensive than planning systems. Information systems for planning require only rapid compute-speed. Requests and replies can be made by means of relatively slow speed devices and displays can be less sophisticated than those in tactical systems.

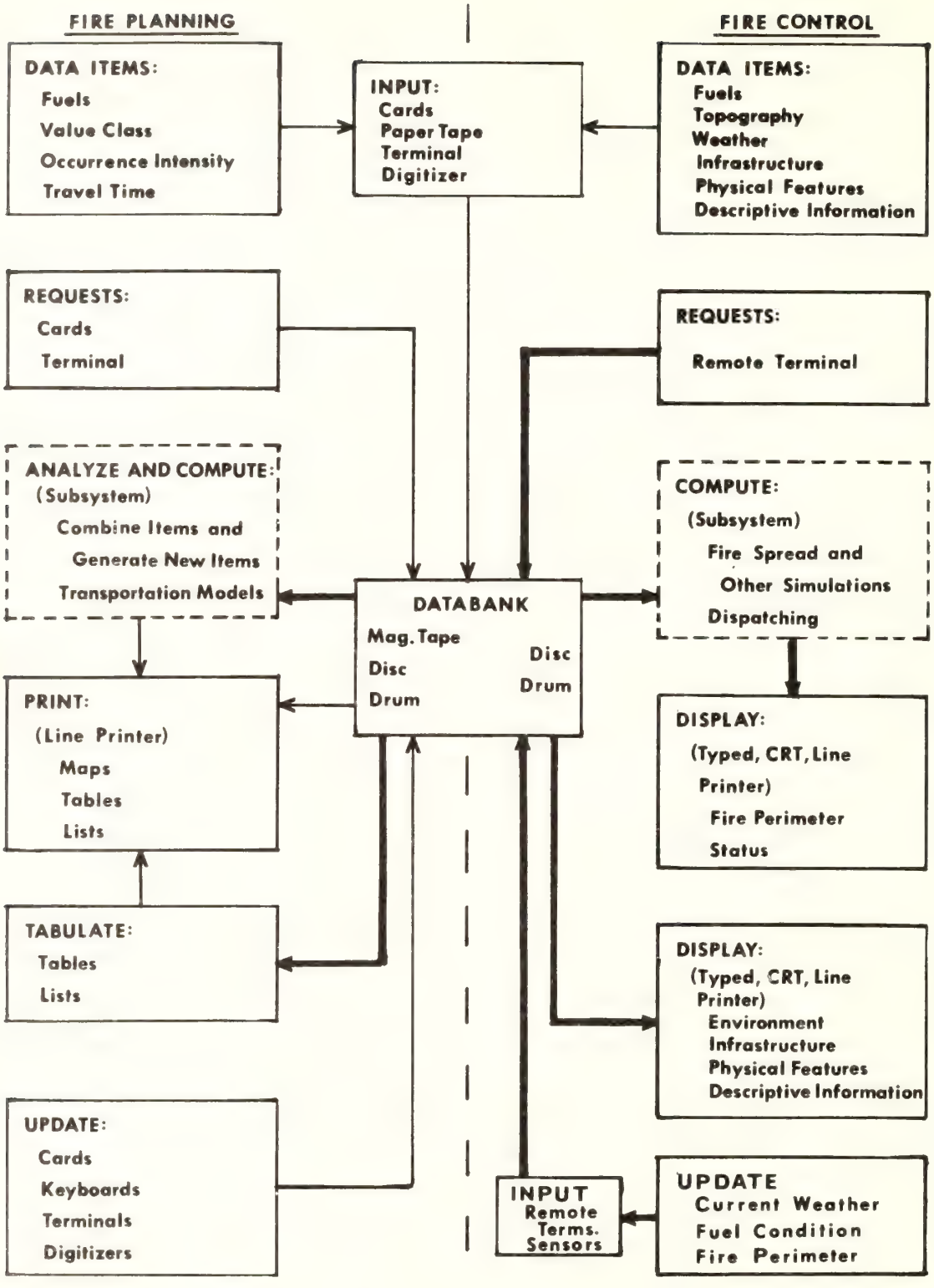


Figure 1.–*Concept of INFORMAP–a computerized system for storing, manipulating, and displaying data–as applied to fire planning and fire control. Arrows show the computer operation required and the direction of flow of data resulting from the operation; width of arrow the relative speed of operation required.*

Tactical Systems

Probably the most advanced tactical information system is the U.S. Air Force's SAGE system of air defense (Burck 1965; Gentle 1965). SAGE, or Semi-Automatic Ground Environment, can compute and display almost instantaneously on wall-size outline maps the actual and predicted movements of aircraft and missiles anywhere in the Northern Hemisphere. Radar and other electronic sensors acquire data on the location and movement of airborne objects which are fed into computers.

Industry has developed computerized information systems to store and retrieve data. Westinghouse Electric Corporation has developed a tactical system to provide current information on production, sales, and market conditions to top management in real time (Burck 1965). Current information can also be stored and used for longer-range planning. Lockheed Aircraft Corporation also is successfully using a computerized system to control production and inventory. American Airlines' SABRE system for airlines reservations is another example of the use of a computerized system. SABRE also uses stored data to analyze traffic, flights, and profitability.

The Los Angeles City Fire Department is using computer processes to simplify and automate predetermined command and control procedures, such as dispatching, communications, inventory, retrieval, and determining status of men and equipment (Nielson and Ryland 1968). Its system does not include map digitizing and display or the ability to compute and display fire spread or other simulations.

Planning Systems

Among the computerized planning systems in operation is a system for inventorying resources destroyed and remaining after a nuclear attack on the United States (Lewicke and Gaskill 1961). It was developed for the U.S. Office of Emergency Planning. Data are stored by a system of grid cells, and the grid is referenced to map coordinates. The system is designed primarily for inventory of physical and human resources rather than for the inventory and analysis of land use and for displaying map locations of geographic features, roads, and developments. It does not operate in real time.

Probably the most advanced system for actual inventory and display of land use and resources is being developed for the Canadian Government's inventory program (Tomlinson 1967). Named GeoIS (for Geographic Information System), it includes an automatic scanning device, an XY digitizer, and an IBM System/360 Model 65 computer.

An example of an operational computerized system for wildland management planning information is MIADS2 (Map Information Assembly and Display System) (Amidon 1966). Area-type map information is coded by rectangular cells and punched on computer cards. These data can be stored, updated, summarized, and multiplied by factors in the computer. Results can be displayed by computer line printer as maps, lists, or tables. MIADS2 is adequate for fire planning, but we consider the 2-code spaces per cell and the 2-digit codes too limited for fire control applications and for multiple-use management involving many forestry activities. The second limitation of MIADS2 for our purpose is that data are not referenced to a map coordinate system. A referencing system is particularly vital for conversational, real-time remote terminal operations, as for example, during a fire. The third limitation is this lack of real-time random access capability. Random access of data files in the computer is essential to meet the time requirements of INFORMAP.

Several computerized contour digitizer systems to speed the preparation of contour maps have been developed (Konecny and Refoy 1968; Stoll 1968; Shepherd 1968). This type of equipment shows promise for speeding the coding of data for INFORMAP.

STATUS OF INFORMAP

In Fire Planning

INFORMAP for fire planning is a batch processing operation, because a fire planning system does not require the rapid turnaround and processing time of a tactical system.

INFORMAP uses most of the data items now used in Forest Service fire planning, designating them as Fire Environment Item codes. Items include land value class, fuel hazard zone, and past fire frequency. INFORMAP can sum acreages of one item at a time, by classes, and print the sums in tabular form. It can produce as 12-inch square printouts from one to five of the items—one at a time or in combination. The printouts match the scale of the standard Forest Service base map, and are automatically aligned to

the standard coordinate system of map references appearing on it. The system can update stored data to reflect changes.

In Fire Control

For fire control applications, INFORMAP uses most of the data items needed by plans and intelligence sections, designating these data by Fire Control Item codes. Items include, roads, trails, ridges, existing handlines, firebreaks, slope, and aspect. INFORMAP produces the same type of output for fire control as it does for fire planning—12-inch square printouts. And any of the data items used in fire planning can also be used in fire control application. Data items that would change during a fire have not yet been entered into the system, such as wind speed and direction, temperature, humidity, and fire perimeter from airborne scanners.

INFORMAP's manual coding and reference methods are much too slow for updating items that change during a fire. Magnetic tape is unsatisfactory for bulk data storage because it cannot be manipulated with the speed and flexibility necessary for fire control systems. Requesting computer output by punchcards is unsatisfactory for the same reasons, though the high-speed line printer is itself satisfactory for producing the output. But a wider choice of output devices and forms of display is needed; this is being studied. We are also still unable to generate printouts from a remote terminal.

The need for an information system that can operate from remote terminals or computers is essential in fire control operations. The operator should be able to interrupt the computer by using simple, conversational commands and have it work on his job and return the results to him quickly. And he should be able to update the many quickly changing variables in a fire situation with equal speed. Items in the program should be accessible to subprograms for computing fire perimeters and other tactical situations. And the results must be available before the actual perimeters have increased appreciably.

CHARACTERISTICS OF INFORMAP

The basic operations of INFORMAP consists of coding, storing items of information, and retrieving and printing out these items. The following procedures apply to INFORMAP for fire control and for fire planning, unless noted otherwise.

Coding and Referencing

Overlay for Coding

A grid overlay is placed on the map to be coded. Coding is done manually using prescribed characters. The overlay is divided into *Dataspaces, Datacells,* and *Matrixes.*

The *Datacell,* the basic building block, contains 15 *Dataspaces* arranged in three rows of five spaces each—filled by a code character. The character is printed out in the same position that it was entered. A *Matrix* or data module, consists of 576 Datacells (24 Datacells wide by 24 high) and 8,640 Dataspaces (576 Datacells x 15 Dataspaces per Datacell). Therefore, 8,640 Dataspaces or characters must be coded per *Matrix* provided all Dataspaces are used.

INFORMAP presently contains two "sets" of data, one each for fire planning data items and fire control data items. The two sets use different codes, must be coded on separate overlays, and double the amount of coding required to 17,280 characters per *Matrix.* Additional sets can be added as the need arises by changing the programing. The data in each set are handled differently in the computer.

Codes

Each set of data in INFORMAP has a theoretical maximum capacity of $(48)^{15}$ or 1.66×10^{25} codes using all possible combinations of the 15 Dataspaces in a Datacell and the 48 alphanumeric characters available in the standard character set of the computer line printer. However, codes 15 characters long are difficult to handle and interpret. For the present we have limited to four characters the maximum length of code for any single item in INFORMAP. For example the 11 data items in the fire planning set are assigned to specific single Dataspaces (7 items) or to pairs of Dataspaces (4 items) among the 15 available in the Datacell. And each is assigned a limited number of single-character code or 2-character code, described in detail later. Thus, fire planning INFORMAP as now programed provides for only 9,552 possible combinations per set (7 items X 48 characters + 4 items X $(48)^2$ characters) instead of the 1.66×10^{25} combinations theoretically available.

So far as possible codes for each item were given mnemonic value or were made identical to the standard numbers, letters, or symbols used on maps

and lists in fire management. This way, the codes are more easily interpreted when printed or displayed. For example, the 17 fire fuel types recognized by the California Region of the Forest Service are coded from 01 to 17. And the fire control item Highway is assigned the code character H.

Card Preparation

Data and programs are entered by punch cards. One row of a Matrix representing 120 Dataspaces or characters (5 columns per Datacell X 24 Datacells per Matrix) is keypunched on two cards. Each Matrix requires 144 cards (2 cards per row X 3 rows per Datacell X 24 Datacells per Matrix). Each square mile on a map requires 960 Dataspaces of codes, or 16 punchcards.

Referencing System

Each Matrix is referenced to latitude and longitude by the California Coordinate System (CCS) of map reference, part of the United States Coordinate System (Mitchell and Simmons 1945; *fig. 2*). Most National Forest base maps are marked at 2-1/2-minute intervals on the CCS scale. At the map scale adopted for INFORMAP, one or more of these references marks for latitude and longitude are in each Matrix. The marks are coded on the border of each Matrix and are printed out. Matrixes are called out of storage by their coordinates. For example, a fire manager wanting information on conditions in the vicinity of a certain fire would ask for the information by specifying to the computer the nearest latitude and longitude marked on the map and names of the items of information desired.

Map Scale

For convenience in developing INFORMAP, a map scale of 4 inches = 1 mile, an area coding minimum of 10 acres, and a Matrix size of 5,760 acres, or 9 square miles, have been adopted as standard *(fig. 2; table 1)*. At this scale, 10 acres or one Datacell is represented by a square 1/2 inch by 1/2 inch on both the map and computer printout. A Matrix is represented by a square 12 inches by 12 inches or 24 Datacells by 24 Datacells on both the map and printout, or 3 miles by 3 miles ground measurement.

The coding minimum (10 acres) exactly matches the dimensions of the Datacell on the coding grid and on the computer printout. There is also space for an adequate number of coding items, and for entering code by hand in each Dataspace. For use in orienting and interpreting the printout, particularly in fire control applications, it usually is necessary to overlay it on the corresponding National Forest topographic base map. It is most convenient if both are of the same scale rather than resorting to optical projection devices to match scales.

As the first step in preparing data for coding, assemble the necessary map data and enlarge or reduce the maps as necessary to the standard 4 inches = 1 mile scale. Next, prepare a grid overlay for hand coding the map data. Each Dataspace on the overlay grid for coding is 1/10-inch wide by 1/6-inch high.

But any coding minimum can be used for INFORMAP. Table 1 is a partial listing of map scales and corresponding ground dimensions and areas for the standard-sized 1/2-inch by 1/2-inch Datacell and the 12-inch by 12-inch Matrix. A smaller coding minimum yields greater precision—a desirable characteristic in fire control applications of INFORMAP, particularly for fire spread simulations and displays of fire perimeters.

The scale of the grid overlay for coding can be matched to the map scale rather than the other way around. But we do not recommend it be done. Computer printer output can be programed to a

Table 1.—*Datacell and Matrix dimensions for various map scales for the standard-sized coding overlay and computer output*

Map scale	Datacell		Matrix	
	Length of one side	Area	Length of one side	Area
		Acres		*Acres*
8 inch = 1 mi. (1:7,920)	5 chains (330 ft.)	2.5	120 chains (1.5 mi.)	1,440
[1] 4 inch = 1 mi. (1:15,840)	[1] 10 chains (660 ft.)	[1] 10	[1] 240 chains (3 mi.)	[1] 5,760
2 inch = 1 mi. (1:31,250)	20 chains (1/4 mi.)	40	480 chains (6 mi.)	23,040
1 inch = 1 mi. (1:62,500)	40 chains (1/2 mi.)	160	960 chains (12 mi.)	92,160
1/2 inch = 1 mi. (1:125,000)	80 chains (1 mi.)	640	1,920 chains (24 mi.)	368,640
1/4 inch = 1 mi. (1:250,000)	160 chains (2 mi.)	2,560	3,840 chains (48 mi.)	1,474,560

[1] Standard for developing INFORMAP.

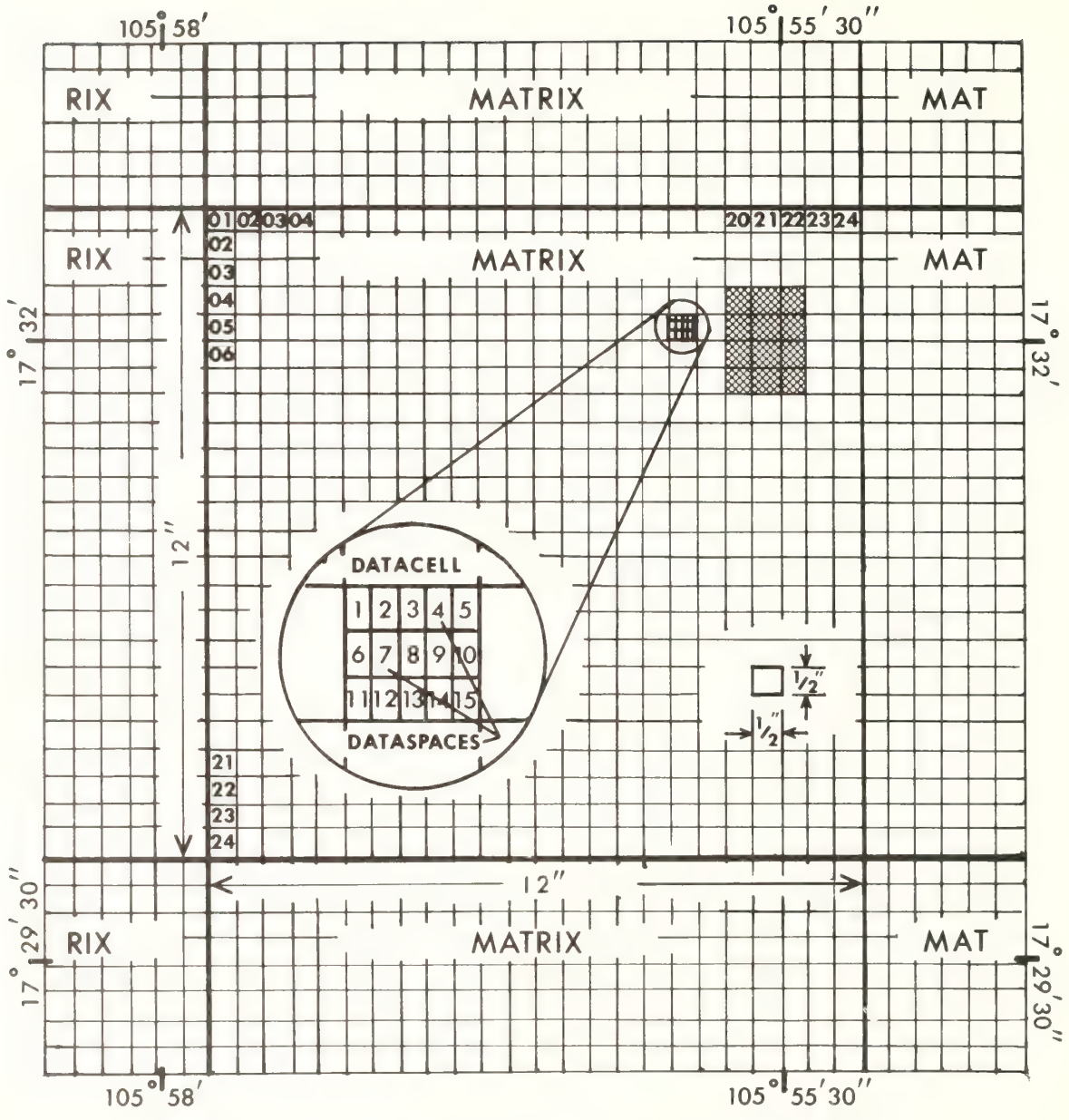


Figure 2.–*Processing data for INFORMAP starts with coding each data item in one or more Dataspaces. Each Datacell has 15 such spaces. Each 12- by 12-inch Matrix consists of 576 Datacells. Printouts are in Matrix form and size. Shaded area is shown coded in fig. 3.*

limited number of other scales by printing in every other space, every third space, etc. This procedure results in insufficient resolution, however, for most fire uses.

Coding

Data are entered into INFORMAP initially by hand coding. However, once the data are in the system, they can be updated rather easily. Many items never change and others change infrequently or slowly.

In the future, it may be possible to use rapid, automatic, electronic methods–such as digitizers and scanners–for coding and inputting data into INFORMAP.

At all times in planning and coding, it is important to keep in mind the needs of the fire crews and other personnel who will be using the

INFORMAP information. They need to know precisely where physical features are, such as access routes, both man-made and natural. Entries must be clear and unambiguous. Every effort should be made to assure that the basic data are accurate. And when better data become available on any item—on value classes or fire fuel types, for example—the item should be updated as soon as possible.

Data Coded in the System

Basic data for developing and testing INFORMAP were supplied by the San Bernardino National Forest. They cover an area of approximately 50 square miles on the Cajon Ranger District. Conditions of fuel, topography, and fire incidence there are fairly typical of those in southern California's mountainous regions. Basic data were extracted from Forest base maps, all of the special maps and map overlays of items used for fire planning, and pre-attack maps and descriptions used for fire control. The data were then coded for entry into INFORMAP.

We also coded some of the same data items on about 60 square miles of the Palisades Ranger District on the Coronado National Forest, Arizona. Data were coded to a 40-acre minimum *(table 1)* rather than the 10-acre minimum used on the San Bernardino National Forest. We wanted to determine the effect of decreased precision, or larger coding minimum, on usefulness of INFORMAP for fire planning and fire control applications.

Three general types of data items are hand-coded, keypunched, and stored on tape: (a) static fire environment, (b) fire control, and (c) library or listed information. They represent the information needed by the Forest Service in fire planning and fire control.

Static Fire Environment Data

The eight Static Fire Environment items in INFORMAP, include slope, aspect, and resource value class *(table 2)*. Each item represents the average condition for the 10 acres. The code, consisting of one or alphanumeric characters, is assigned either one or two specific Dataspaces in the Datacell *(table 2)*.[1] The Static Fire Environment items occupy one "set" of 15 Dataspaces. Each item is divided into several classes from 6 to 76 in number, and each class is assigned a numeric code between 00 (zero) and 75 *(fig. 3)*.

[1] Lists of detailed codes for Static Fire Environment items are available upon request to Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

Four of the five remaining Dataspaces are used to record the coordinates of the particular Datacell in the Matrix: the row in the left-hand pair of Dataspaces and the column in the right-hand pair. This arrangement permits locating a particular Datacell in a Matrix.

The center Dataspace can be used to code Ownership or can be reserved for Fire Perimeter when a fire-spread simulation subprogram is developed. If reserved for fire perimeter, it is to be left blank when coding the other items. Additional Fire Environment items can be added when needed by setting up additional "sets" of Datacells and assigning Dataspaces and codes.

Code all Static Fire Environment items on a blank grid overlay of Datacells and Dataspaces to the appropriate 4 inches = 1 mile base map. A grid one Matrix in size—12 inches by 12 inches, 3 miles by 3 miles ground measurement—has been adopted as standard *(fig. 2)*. This size is easy to handle for hand coding and is the unit used for keypunching the coded data into cards.

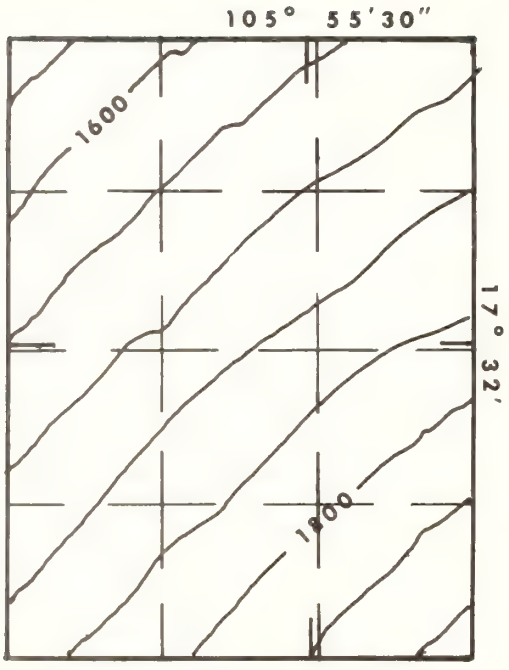
Fire Control Data

The 41 Fire Control items now in INFORMAP are grouped in four categories: Pre-Attack, Infrastructure (highways, roads, etc), Physical, and Other items *(table 3)*. The name Fire Control items was assigned for convenience in distinguishing them from Fire Environment items. Either class of items may be useful in planning and in fire control, and are accessible to programs for planning and control.

The Fire Control items occupy the second "set" of 15 Dataspaces in INFORMAP. These items are coded in the nearest Dataspace(s) to their actual map location. Since each Dataspace represents 2/3 acre (10 acres per Datacell divided by 15 Dataspaces per Datacell) on the ground, the precision of any

Table 2.—*Static Fire Environment items and assigned positions*

Dataspace number in Datacell	Static fire environment item
1	Average slope
2	Aspect
3	Past fire frequency
4 and 5	Average elevation
6 and 7	Datacell coordinate in Matrix (row)
8	Ownership *or* fire perimeter
9 and 10	Datacell coordinate in Matrix (column)
11	Resource value zone
12	Occurrence intensity zone
13	Fuel hazard zone
14 and 15	Fuel type



BASE MAP

CODES

Average Slope

Code No.	Percent
0	0-9
1	10-19
2	20-29
3	30-39
4	40-49
5	50-59
6	60-69
7	70-79
8	80-89
9	over 100

Average Aspect

Code No.	Description
0	North
1	East
2	South
3	West
4	Northeast
5	Southeast
6	Southwest
7	Northwest
8	Ridgetop
9	Flat

Average Elevation

Code No.	Amount (200's of feet)
00	0 - .5
01	.6 - 1.5
02	1.6 - 2.5
⋮	⋮
75	74.6 - 75.5

CODED OVERLAY

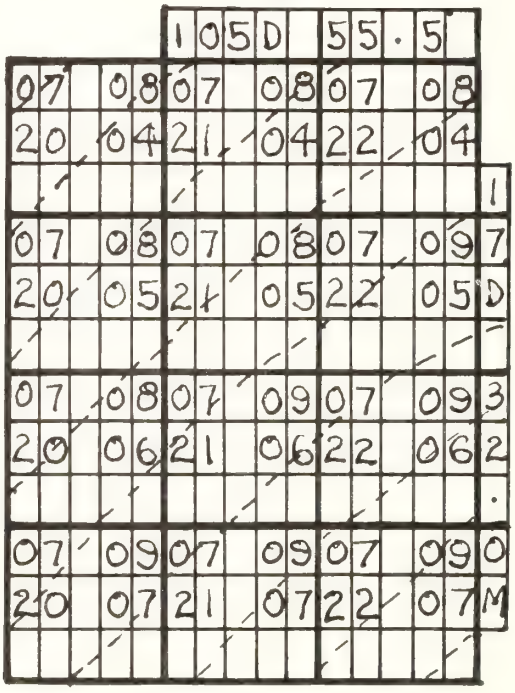


Figure 3.–*Static Fire Environment items of slope, aspect, and elevation; Datacell coordinates; and Matrix coordinates are coded for a portion of one Matrix (shaded area in fig. 2).*

Pre-Attack item is 2/3 acre. Any of the 15 Dataspaces can be used to record data.

As many Dataspaces as necessary should be coded to show accurately the position of the particular feature. For example, a road (Infrastructure) traversing a Datacell might be coded in five adjacent Dataspaces, all with the same symbol. On the other hand, a helispot might require only one Dataspace. Occasionally, when several features occur in one Datacell, it may be necessary and desirable to arrange the coding so that all features are represented. This may mean omitting some of the string of code symbols—for a road or trail, for example—and coding in a helispot location. The coding should be done so that each feature is clearly identifiable—just like an actual map *(fig. 4)*.

Table 3.—*Fire control items and codes*

Code symbol	Item
	PRE-ATTACK
C	Tractor line – proposed
D	Tractor line – existing
F	Tractor line and all-wheel drive – proposed
G	Tractor line and all-wheel drive – existing
M	Handline – proposed
N	Handline – existing
I	Firebreak – tractor
J	Firebreak – all-wheel drive
K	Firebreak – hand
A	Outline of barrier
/	Boundary of blocks
V	Dead-end of C,D,F,G,M,N,I,K
XT	Tractor loading location
XW	Water source – existing
XP	Helispot – proposed
XE	Helispot – existing
XL	Helispot – all size helicopters
XR	Heliport – proposed
XH	Heliport – existing
XC	Fire camp
XA	Staging area
XS	X spot (rocks, etc.)
XG	Guard station
XR	Ranger station
XD	Equipment depot
	INFRASTRUCTURE
H	Highway
R	Road
T	Trail
L	Railroad
P	Power line
Q	Telephone line
U	Deadend of R, T
	PHYSICAL
E	Ridge
S	Stream, river, canal
W	Water body outline
Y	Canyon or draw bottom
PK	Peak
RS	Reservoir
	OTHER
XX	Referenced intersections of fire control features and infrastructure
Z	Latitude and longitude information,2-1/2 minute increments

Fire Control items are not broken down into classes as was done with Fire Environment items. Such a division is not necessary for planimetric features.

Pre-Attack items.—Many of the National Forests, particularly in the California Region, prepare fire pre-attack plans which describe such fire control points as ridge tops and fuel-breaks that are potentially defensible as firelines, water sources, and tractor unloading sites. The 25 Pre-Attack items in INFORMAP *(table 3)* include all of the data items used for such pre-attack planning.

Pre-Attack items can be coded directly from the pre-attack maps onto the INFORMAP grid overlay provided the scales match *(fig. 4)*. If scales do not match, the map will have to be brought to the standard 4 inches = 1 mile scale. Usually, the pre-attack items are delineated on the standard Forest topographic base map. Four categories of Fire Control items could then be coded at one time.

Infrastructure items.—All seven Infrastructure items (roads, trails, etc.) are planimetric map-type items similar to many of the Pre-Attack items *(table 3)*. Most of these items are shown on the Forest base map. They can be coded directly on the grid overlay, provided the map scale is correct *(fig. 4)*.

Physical items.—Six Physical items are now incorporated in INFORMAP *(table 3)*. Included are ridge, stream, etc. All are shown on the Forest topographic base map. They can be coded directly on the INFORMAP grid overlay, provided the map scale is 4 inches = 1 mile *(fig. 4)*.

Other items.—Two items of miscellaneous or supplemental information are included in INFORMAP *(table 3)*, and each is coded in its exact map location. Referenced intersections of Pre-Attack items and Infrastructure mark, for example, the termini of a preplanned Handline. "Z" designates latitude and longitude information for orienting printed INFORMAPs on Forest base maps. Both latitude and longitude are coded on the grid overlay so that the actual coordinate line passes between the degree and minute symbols *(figs. 3,4)*.

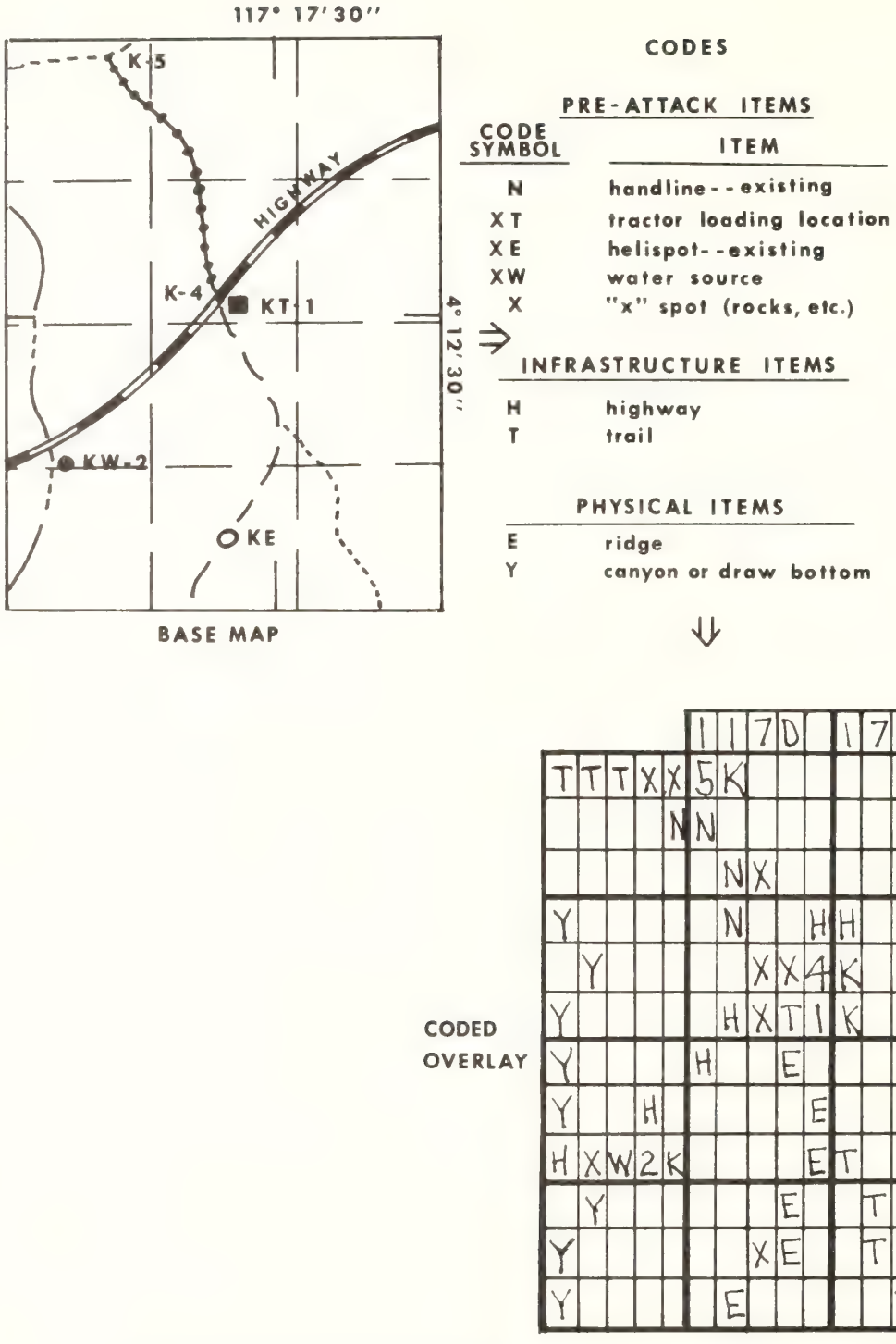


Figure 4.--*Nine Fire Control items plus Matrix coordinates of latitude and longitude are coded for a portion of one Matrix in pre-attack block "K."*

Library Data

The one type of Library or listed information in INFORMAP has data on pre-attack line, fire camp locations, tractor unloading locations, and other items shown in the pre-attack maps prepared by the National Forests. It provides supplementary data on the Pre-Attack items described earlier; for example, the length, slope, difficulty of building a line, and type of force required, are listed for specific sections of fireline. Library Information is highly useful for fire control applications. This information is a reproduction of the pre-attack books, uses similar format, and is available from the Forest for coding.

Output from the System

Requests for Data

To obtain INFORMAP printouts or a listing of Library Information, the user need only know what information he wants out of the system, the proper commands to use, and how to punch and enter cards in the card reader. Major command words used are: "STANDARD OUTPUT" for Static Fire Environment items, "PLOT DATA" for Fire Control items, and "LIST DATA" for Library items. If one of these key words is not found in the input cards, the computer immediately tells the operator that he has made an impossible request. The program then branches back to the starting position and is ready for a new command.

Printouts

Printouts are produced one at a time as 12- by 12-inch Matrix. These modular units can be used individually or joined together to form map overlays of larger areas *(fig. 5)*. Fourteen-inch-wide computer line printer sheets can easily accommodate the size of the Matrix.

Static Fire Environment items ordinarily will be called for and printed one at a time; occasionally two at a time. Additional items are best called for and printed separately. Since the printer paper is translucent, two printouts can be overlaid one on the other and on base maps for comparing features. The separation makes them easier to assimilate.

To obtain Static Fire Environment information, the fire planner needs only know the longitude and latitude (nearest 2-1/2 minutes) of the area that he

Figure 5.–*INFORMAP printouts of selected Fire Control items can be used as overlays to base maps.*

desires to look at. Then, using the computer card reader, the operator enters the command words, "STANDARD OUTPUT," and the longitude and latitude. Next, if he desires to see the fuel types for this area, for example, he simply enters the command words, "FUEL TYPE." The computer then searches the magnetic tape until it finds the proper area. The requested data is then printed out on the high-speed line printer in the following order: latitude and longitude requested, the words "STANDARD OUTPUT," and the words "FUEL TYPE."

The fuel types for the area are then printed out *(fig. 6)*. Printouts may be used directly as maps or as scale overlays to a standard Forest Service base map. Fuel type boundaries may be delineated by hand if desired *(fig. 6)*. The Datacell Coordinates can be printed just below the fuel type data in each Datacell. This printing is for reference purposes only and may be eliminated by entering the word "SUPPRESS" immediately behind the command words "FUEL TYPE" *(fig. 6)*. Map coordinates latitude and longitude are printed out on the right-hand and top margins, respectively, in their proper map locations to aid in orienting the INFORMAP on the base map.

The second type of data which the program handles is designated Fire Control items. Data are also plotted on the high-speed printer. The user may actually plot to map scale such map features as highways, roads, trails, and power lines *(figs. 5,7)*.

Since Fire Control items involve patterns and pattern recognition more items can be assimilated at one time. Up to five items can be called up or plotted at one time, except for Pre-Attack items prefixed by the symbol "X" *(table 3)*. These are all printed out whenever any one of them is requested. Fire Control items cannot be summed, combined, tabulated, or

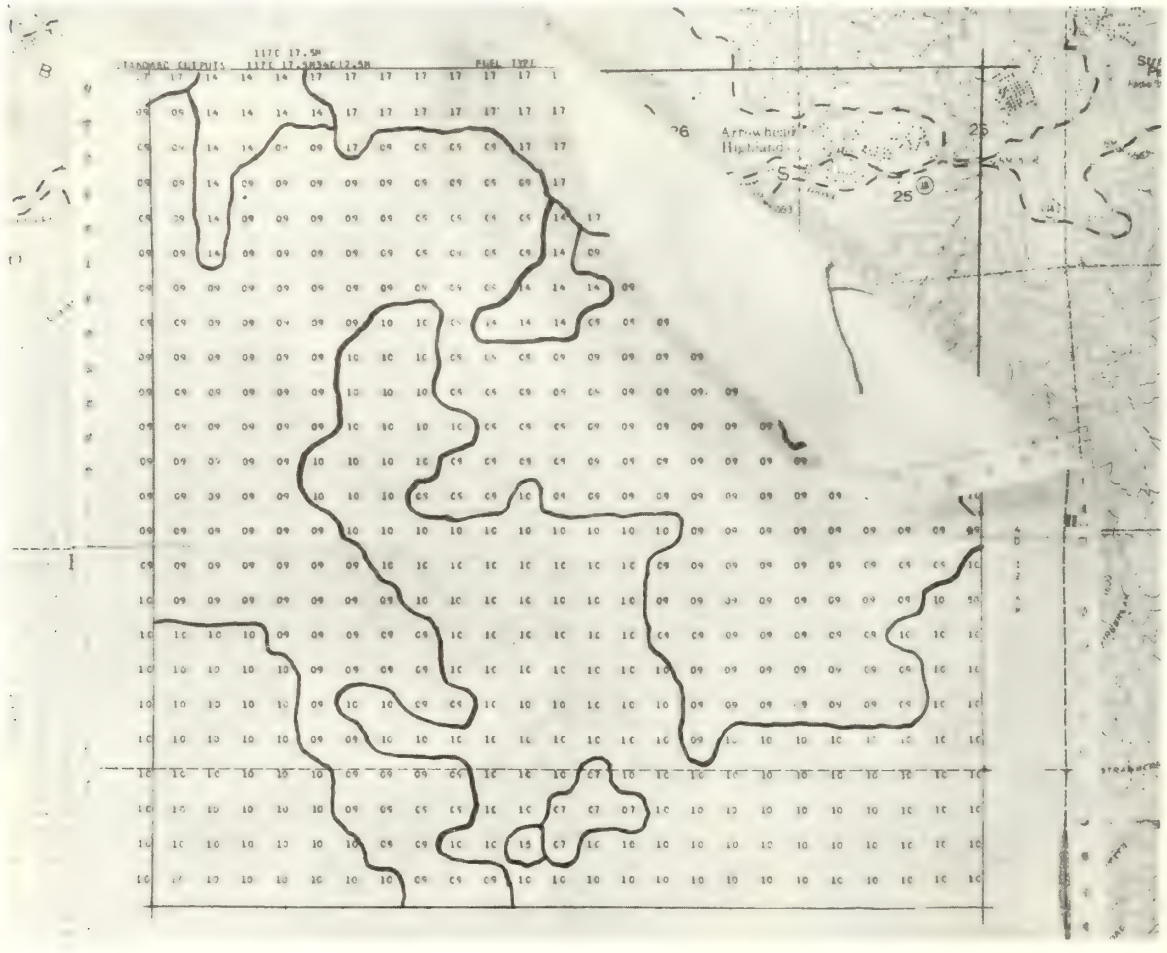


Figure 6. –*Computer line-printer display of one Matrix of the Fuel Type from Fire Environment items. Type boundaries have been delineated by hand for emphasis.*

otherwise manipulated as was the case with Static Fire Environment items.

To obtain information on Fire Control items, a fire planner would enter by cards the command words "PLOT DATA," give the longitude and latitude of the area he wished plotted, and name the features that he wished to plot. For example, if he wished to plot trails, roads, staging areas, highways, and proposed cat lines, he would merely enter the command words "TRAILS," "ROADS," "XA," "HIGHWAYS," and "CAT LINE PRO" (for proposed). The computer would then answer, printing out the longitude and latitude of the area requested and a scale map overlay of the requested items, represented by assigned symbols *(fig. 7)*. For example, highways are represented by the letter H, roads by the letter R, and trails by the letter T. If a requested item does not exist in the given map section (i.e., roads), it obviously would not show on the map overlay.

The third type of data is pre-attack information in verbal form all the information about pre-attack blocks that has been collected by the National Forest. Information on up to ten blocks can be given in one interrogation.

Typical information desired might be locations of water, fire camps, and tractor unloading sites; and characteristics of length, slope, and the fuel resistance to control of a certain section of line. To retrieve this information from the computer, the interrogator need only enter by means of cards the command words "LIST DATA," and give the specific code for the pre-attack block for which information is desired. For example, if he wanted to know everything about lines N_1 to N_2, N_1 to N_3, and N_3 to N_4 in the N block, he would simply enter the code, "N BLOCK,"

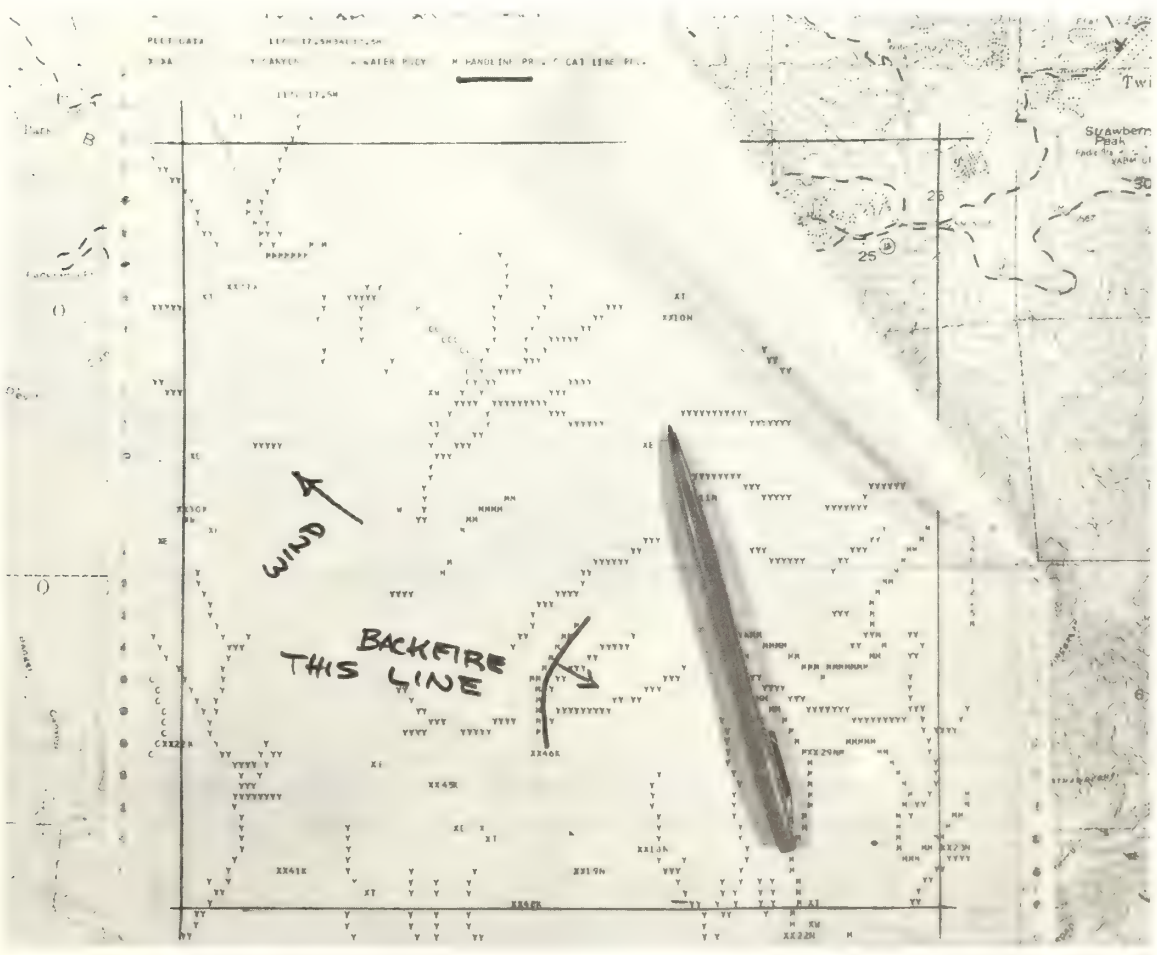


Figure 7. *Computer line-printer display of five Fire Control items. All X-type Pre-Attack items (X), canyon (Y), water body (W), handline (M), and cat line proposed (C).*

and "FILES REQUESTED." The computer would proceed to print out all data that it had about these lines *(fig. 8)*. In our example, the databank contained no information on line N_1 to N_3, so this request could not be filled.

Sumations and Updating

The ability to sum, by acreage, and to combine items of data is vital in fire planning and fire control. Acreages of any Dataspace in INFORMAP can be summed, but acreage summaries are not useful for Fire Control-Type items.

Information in the INFORMAP system can be updated rapidly for any reason; for example, fire-induced changes in the fuel type. If the longitude and latitude of a given matrix are known, a new deck of cards containing the changes is punched. The only data that appear on these cards are the desired changes. The updated data are then read by the card reader, and the desired changes are made automatically on the magnetic tape.

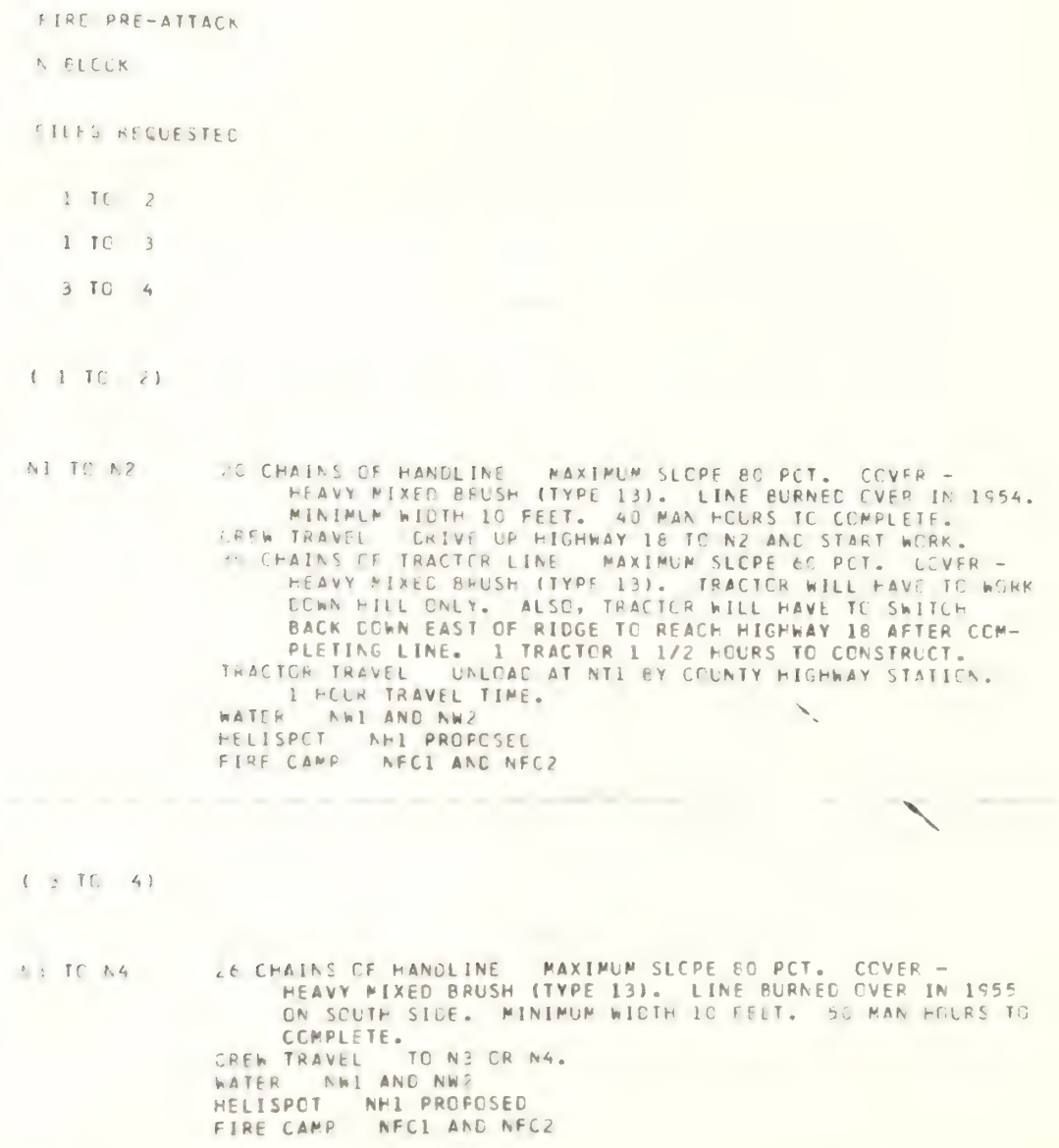

FIRE PRE-ATTACK
N BLOCK
FILES REQUESTED
1 TO 2
1 TO 3
3 TO 4
(1 TO 2)
N1 TO N2
20 CHAINS OF HANDLINE MAXIMUM SLOPE 80 PCT. COVER -
HEAVY MIXED BRUSH (TYPE 13). LINE BURNED OVER IN 1954.
MINIMUM WIDTH 10 FEET. 40 MAN HOURS TO COMPLETE.
CREW TRAVEL DRIVE UP HIGHWAY 18 TO N2 AND START WORK.
40 CHAINS OF TRACTOR LINE MAXIMUM SLOPE 60 PCT. COVER -
HEAVY MIXED BRUSH (TYPE 13). TRACTOR WILL HAVE TO WORK
DOWN HILL ONLY. ALSO, TRACTOR WILL HAVE TO SWITCH
BACK DOWN EAST OF RIDGE TO REACH HIGHWAY 18 AFTER COM-
PLETING LINE. 1 TRACTOR 1 1/2 HOURS TO CONSTRUCT.
TRACTOR TRAVEL UNLOAD AT NT1 BY COUNTY HIGHWAY STATION.
1 HOUR TRAVEL TIME.
WATER NW1 AND NW2
HELISPOT NH1 PROPOSED
FIRE CAMP NFC1 AND NFC2
(2 TO 4)
N3 TO N4
26 CHAINS OF HANDLINE MAXIMUM SLOPE 80 PCT. COVER -
HEAVY MIXED BRUSH (TYPE 13). LINE BURNED OVER IN 1955
ON SOUTH SIDE. MINIMUM WIDTH 10 FEET. 50 MAN HOURS TO
COMPLETE.
CREW TRAVEL TO N3 OR N4.
WATER NW1 AND NW2
HELISPOT NH1 PROPOSED
FIRE CAMP NFC1 AND NFC2

Figure 8.–*Computer line-printer display of Library items of supplemental Pre-Attack information for a portion of block "N."*

FUTURE DEVELOPMENT

We have made more progress to date in developing INFORMAP for fire planning than for fire control. One reason is that the potential advantages of INFORMAP are more readily apparent in the planning application than in the control application. Also, the state-of-the-art and the development costs in computer hardware and software are more favorable for planning than for control applications. For planning, INFORMAP uses stored items directly in a batch process to prepare maps and summary tabulations. And it does so faster and with less work than present methods of data processing. The hardware and software to accomplish this on a research basis are presently within our means.

For fire control applications, however, the system also needs to use stored data indirectly, for example, to compute fire perimeter, to determine how to allocate fire suppression forces, to simulate fire suppression action and results. It should respond quickly (in "real time") to requests for such information, and it should display the information in ways that allow the fire manager to evaluate conditions rapidly.

Progress in developing such capabilities will depend largely upon advances in the state-of-the-art in computer hardware and software. Experience with coding and computer operation of INFORMAP for planning applications on the San Bernardino National Forest has shown that we are already pushing the state of the art for fire control operations. Moreover, we must recognize that adoption of a computer-based fire intelligence system will require a special effort to acquaint fire managers with such unfamiliar techniques. It is likely that costs in fire control applications will be higher not only for system operation, but also for research and development, than in planning applications.

Long-range plans for development include work to:

- Add and code more Static Fire Environment, Fire Control, and Library data items as the need for them is identified. We also intend to keep in mind the types of data and manipulations required in applying INFORMAP to other resource management purposes.

- Identify and code Dynamic Fire Environment data items, such as speed and direction of wind, temperature, humidity, fire danger—all of which may change rapidly during a fire and are vital in evaluating fire behavior. These data are needed in subprograms of fire spread and other simulations.

- Investigate electronic digitizers, scanners, and remote sensors for speeding up data input and for updating stored data.

- Improve the programing to compute the intersection of three or more Static Fire Environment items instead of summing only one item; for example, acres of past fire frequency by resource value by slope.

- Investigate, acquire, and adapt to INFORMAP wherever possible, existing database and mapping programs developed by others.

- Develop and test methods for system operation through remote terminals or computers in a fire camp.

- Fit INFORMAP displays to needs of fire intelligence, including means of enlarging and projecting maps produced by computer systems, overlaying base maps, and copying printouts for distribution to field crews.

PACIFIC SOUTHWEST
Forest and Range
Experiment Station

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O. BOX 245, BERKELEY, CALIFORNIA 94701

FIRE WEATHER AND FIRE BEHAVIOR AT THE 1968 CANYON FIRE

Clive M. Countryman Morris H. McCutchan Bill C. Ryan

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The Authors

are headquartered at the Station's Forest Fire Laboratory, Riverside, Calif. **CLIVE M. COUNTRYMAN** heads fire behavior studies. He earned a B.S. degree in forestry (1940) at the University of Washington, and joined the Forest Service the following year. **MORRIS H. McCUTCHAN** is responsible for fire meteorology studies. He received a B.S. degree (1949) in mathematics at Texas Technological College, and an M.S. degree (1955) in meteorology at the University of Wisconsin. After service in the U.S. Air Force, he joined the Forest Service in 1967. **BILL C. RYAN**, also assigned to fire meteorology studies, has a B.S. degree in chemistry from the University of Nevada (1950) and an M.S. degree in meteorology from Texas A. & M. University (1964). After service in the Air Force, he worked for Meteorology Research Inc., for 2 years before joining the Forest Service in 1967.

Acknowledgments

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Fighting a wildland fire has often been likened to fighting a military battle. In battles there are casualties, in spite of efforts to protect the fighters; so there were in the Canyon Fire of August 24, 1968, when seven Los Angeles County firefighters and their foreman were overrun by a fire flareup and fatally burned. The Canyon Fire burned 20,200 acres before it was finally brought under control; this was indeed a major battle in a continuing war against destructive wildfires.

In the intensive investigation that followed the accident, the weather conditions, fuel conditions, and topography in the Glendora Ridge sector, where the accident occurred, were carefully analyzed.

This paper summarizes the information gathered and the conclusions reached as to the influence of these three factors on the behavior of the fire. Obviously, the particular conditions that prevailed here may never be found in another fire. Nevertheless, the specific information about one fire may help to give fire control personnel a better understanding of fire behavior in general, and so help to prevent future accidents.

The Canyon Fire started on August 23, 1968, near Canyon Inn under Santa Ana wind conditions. The Glendora Ridge sector of the fire quickly spread southerly on an expanding front toward the front country above Sierra Madre Avenue in Azusa, California. It also spread easterly along the upper slopes of the south side of Glendora Ridge. The fire then backed down the slopes above Sierra Madre Avenue. It reached the developed area along Sierra Madre Avenue first just east of the San Gabriel Canyon. Although occasionally hard pressed, the firemen were able to stop the fire as it reached the toe of the main slope. However, the fire continued to spread eastward and downslope on Glendora Ridge and eastward along the front country above Sierra Madre Avenue.

By morning of August 24, the eastward spread of the fire on the upper slopes of Glendora Ridge had been stopped along the firebreak above Azusa Pacific College. The fire also has not crossed the lower half of the firebreak on the spur ridge above Los Angeles County Fire Station 97. The open fireline thus extended east and west between these two firebreaks *(fig. 1)*.[1] In this area, the fire was backing down the slope toward Sierra Madre Avenue. The relatively slow spread down a steep and broken south slope was characterized by frequent hot fire runs diagonally up the slope as the fire worked its way into favorable positions of fuel and topography. These runs or flareups were most prevalent in the numerous steep ravines and became more frequent and violent as the day progressed and the atmosphere became very unstable. The crew from Camp 4-4 was caught in one of these flareups while working along the wall of a steep ravine.

In the investigations that followed the fire, information was gathered on the weather conditions that preceded and accompanied the fire; on the fuel types present and their characteristics, as determined by sampling of similar unburned material adjacent to the fire area as well as examination of the area itself; and on the topographical features of the accident site. Fire behavior was determined through evidence on the scene and through the accounts of witnesses.

Fire behavior in any instance is the result of the integrated effects of weather, fuel, and topography. In the Canyon Fire, topography and fuel conditions dominated behavior, but the sudden flareup that caused the disaster may have been caused by the atmospheric instability and the surge of the sea breeze into the area.

---

[1]Following photographs courtesy of Mike Castro, *Pomona Progress Bulletin*: cover, figs. 23 to 26.

(Photo by Los Angeles County Fire Department.)

Figure 1.–*Approximate fire front location at 0830 hours on August 24, 1968. See Fig. 22 for topographic map of fire area.*

GENERAL WEATHER SITUATION

The synoptic weather pattern, as well as the local conditions, before and during the fire, were analyzed. Fire danger records were also examined.

Before August 24, 1968

For several days prior to Thursday, August 22, 1968, the synoptic weather situation had changed very little. An upper-level trough along the coast of California had kept temperatures down and humidities up *(fig. 2).* On August 21 low pressure covered the desert areas of southern California and higher pressures existed along the coast *(fig. 3).* This resulted in moderate to strong onshore flow over all the Los Angeles Basin, with the marine air layer extending up to about 1,500 feet. The surface temperatures were below normal as they had been for some time.

By August 22, surface winds had changed generally to a more westerly direction that still allowed onshore flow. The height of the marine layer was about the same as on August 21. Temperatures remained relatively low although they were generally slightly higher than on August 21 *(table 1);* the dewpoint changed little also. The situation altered rapidly, however, after the 22nd. The low center aloft that was over the Rocky Mountains in the morning on the 23rd *(fig. 4)* had moved to eastern North Dakota by the morning of the 24th *(fig. 5).*

A big change in surface conditions occurred on August 23 also *(fig. 6).* The gradient was reversed from the orientation it had on August 21. High pressure had become centered to the northeast of Los Angeles, and there was a Santa Ana condition with a

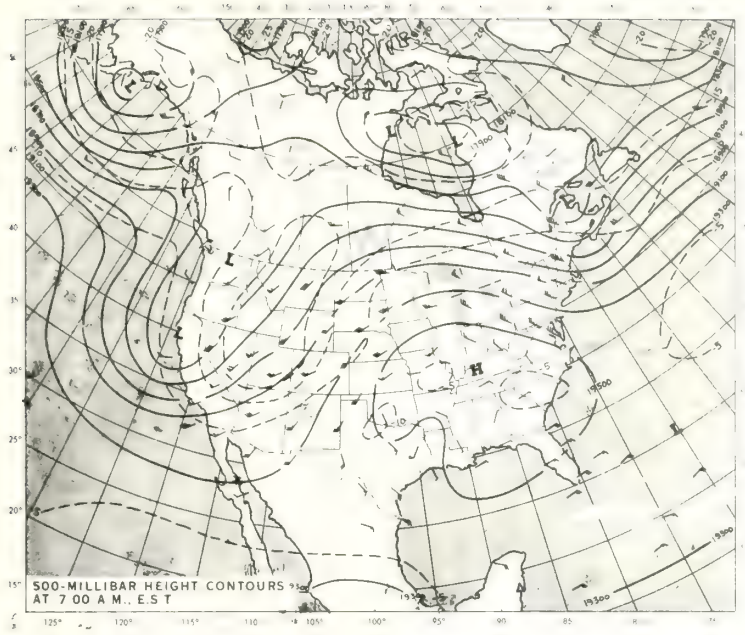

Figure 2.—*500 millibar height contours at 0500 local, August 21, 1968.*

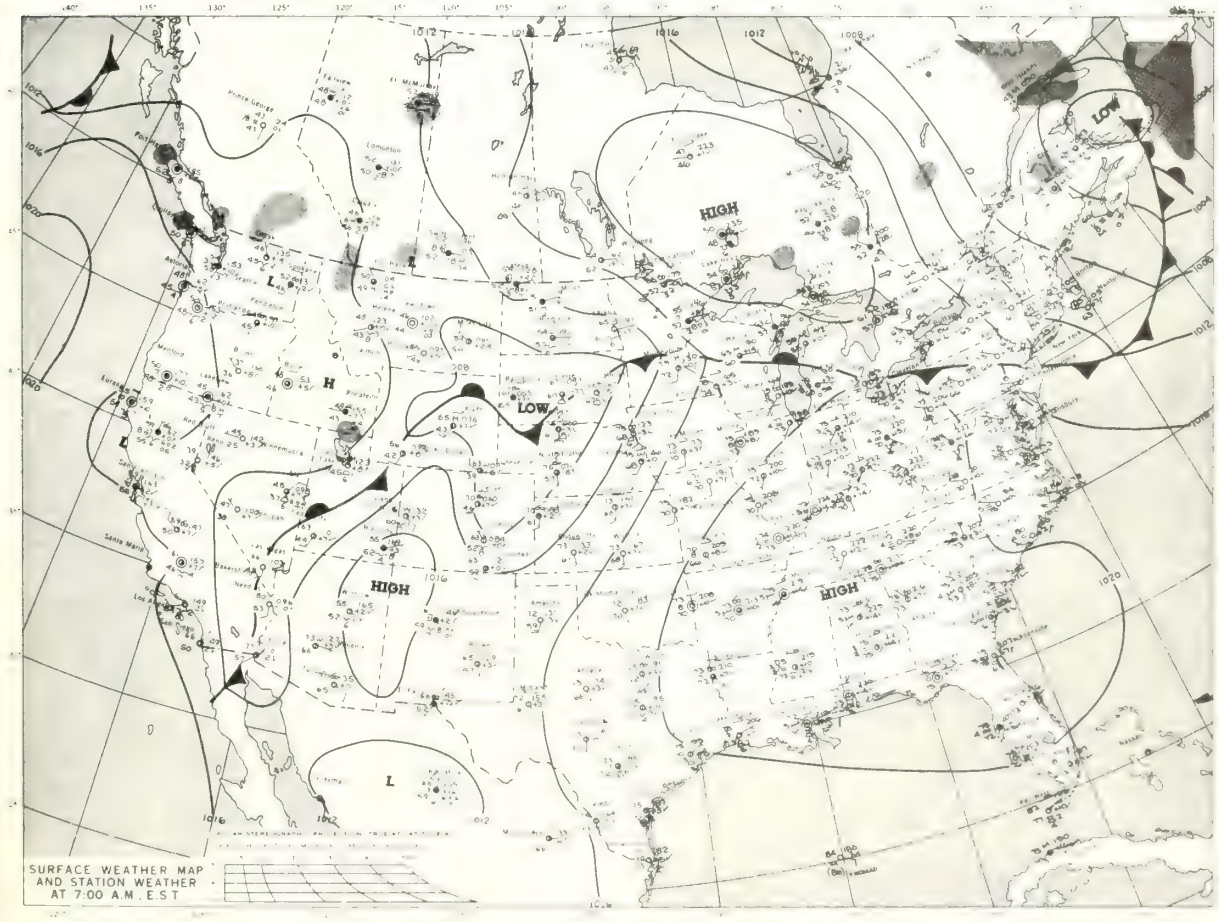

Figure 3.—*Daily surface weather map for 0500 local, August 21, 1968.*

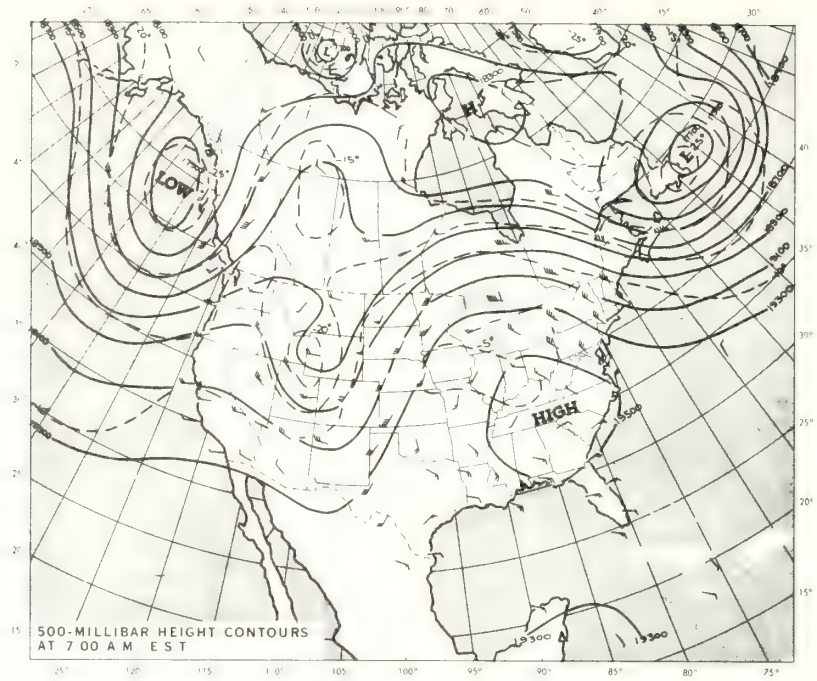

Figure 4.—*500 millibar height contours at 0500 local, August 23, 1968.*

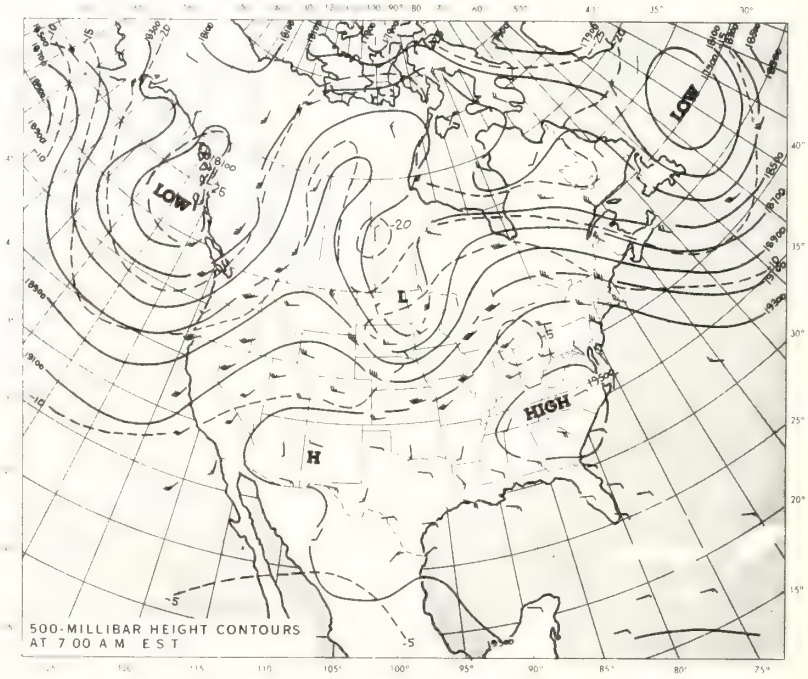

Figure 5.—*500 millibar height contours at 0500 local, August 24, 1968.*

7.8 mb. pressure difference between Los Angeles and Tonopah *(table 1)*. This compared to a 1.4 mb. difference at the same time the day before. The upper-air flow had become anticyclonic on the 23rd. The ridge was over the coast of southern California and temperatures at 500 mb. were high *(fig. 4)*. Temperatures on the surface in southern California also jumped on the 23rd; for example, the temperature at Los Angeles was 90° F. at 1100[2] as compared to 70°F. the day before. Dewpoint temperatures also dropped significantly *(table 1)*. Surface winds were more northerly. Accompanying this increase in temperature, decrease in humidity, and slight change in wind direction was also a large decrease in atmospheric static stability, and the marine layer was eliminated from the coastal area *(fig. 7)*.

[2]All times in this report are Pacific daylight saving time (P.d.s.t.), unless shown otherwise.

Table 1.–*Temperature, wind observations, and sea-level pressure differences, 1100 P.d.s.t., August 21 to 24, 1968*

Date (1968)	Dry bulb temperature	Dewpoint	Wind direction	Windspeed	Pressure difference
	°F.	°F.		M.p.h.	Mb.[1]
			LOS ANGELES		
8/21	69	55	WSW	12	+3.3
8/22	70	57	WSW	12	-1.4
8/23	90	35	N	6	-7.8
8/24	76	65	SW	5	-3.7
			BURBANK		
8/21	74	42	E	6	
8/22	75	57	S	6	
8/23	90	35	NNW	6	
8/24	85	37	SE	7	
			ONTARIO		
8/21	74	52	WSW	6	
8/22	76	50	SSW	10	
8/23	88	44	SE	6	
8/24	87	42	S	7	

[1]Pressure at Los Angeles, California minus pressure at Tonopah, Nevada.

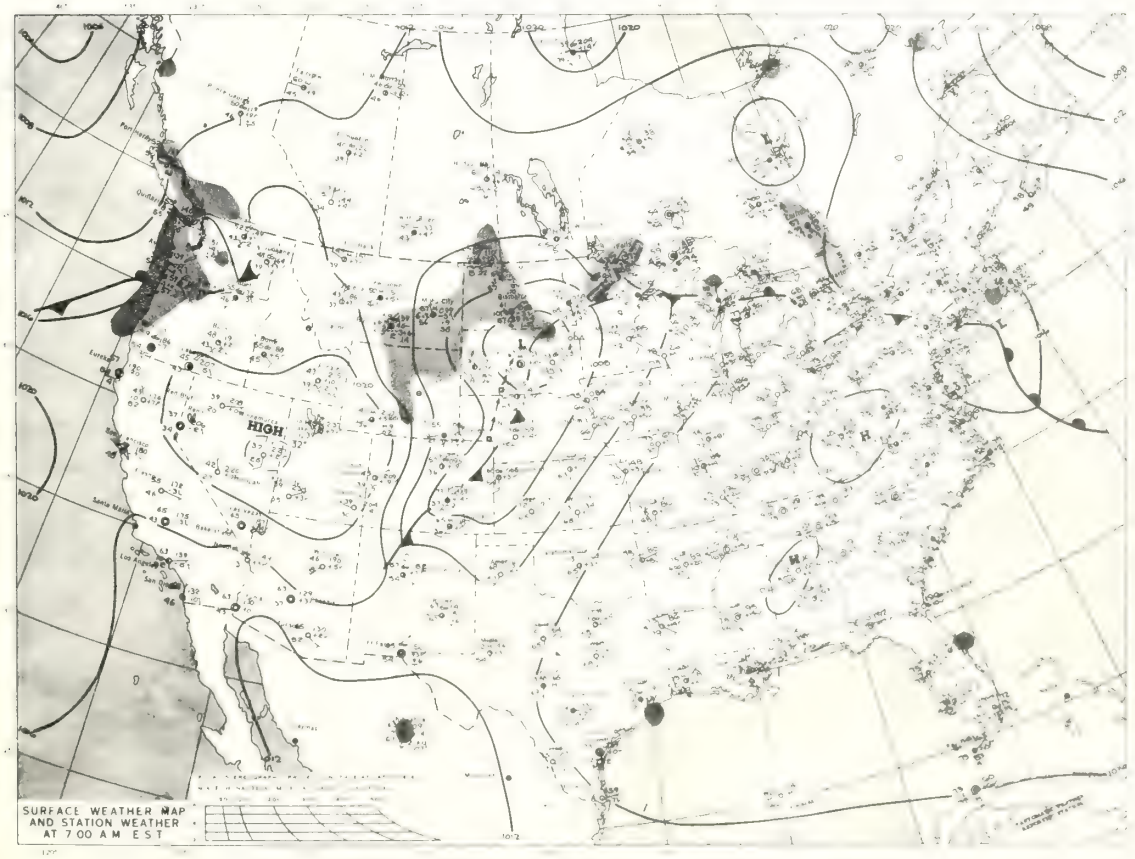

Figure 6.–*Daily surface weather map for 0500 local, August 23, 1968.*

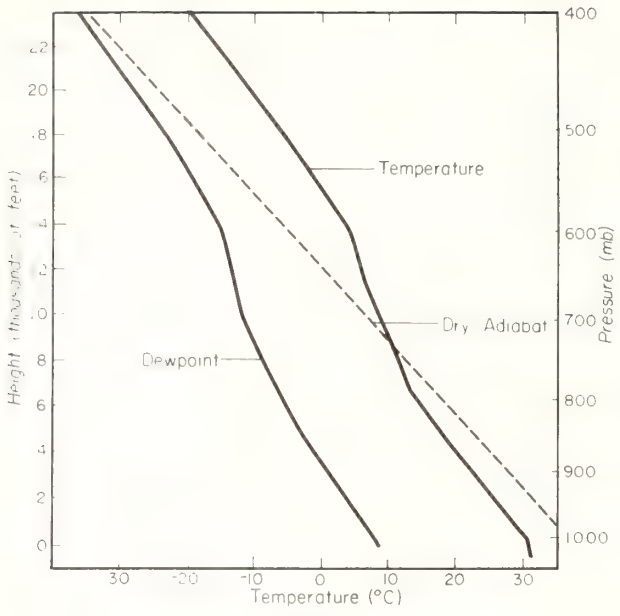

Figure 7.–*Radiosonde observation at Los Angeles, 1300 local, August 23, 1968.*

On August 24, 1968

On August 24, the day of the accident, there were only high clouds and visibility remained over 5 miles in the San Gabriel Valley and foothill region *(table 2)*.

The isobaric pattern formed a surface col area over southern California, so that winds over the area varied considerably in direction and speed *(fig. 8)*. A layer of marine air was evident along the coast, but the low humidities and high temperatures at the fire area indicated the cool, moist marine air did not reach there. Temperatures had begun to fall again, especially near the coast, but were still high away from the coast *(table 1)*.

No sounding at the fire location at the time of the accident is available; but a representative sounding for the fire area was constructed *(fig. 9)* from the sounding made at Los Angeles International Airport at 1300, the surface temperatures at Azusa, and the dewpoint temperatures in the area. The surface

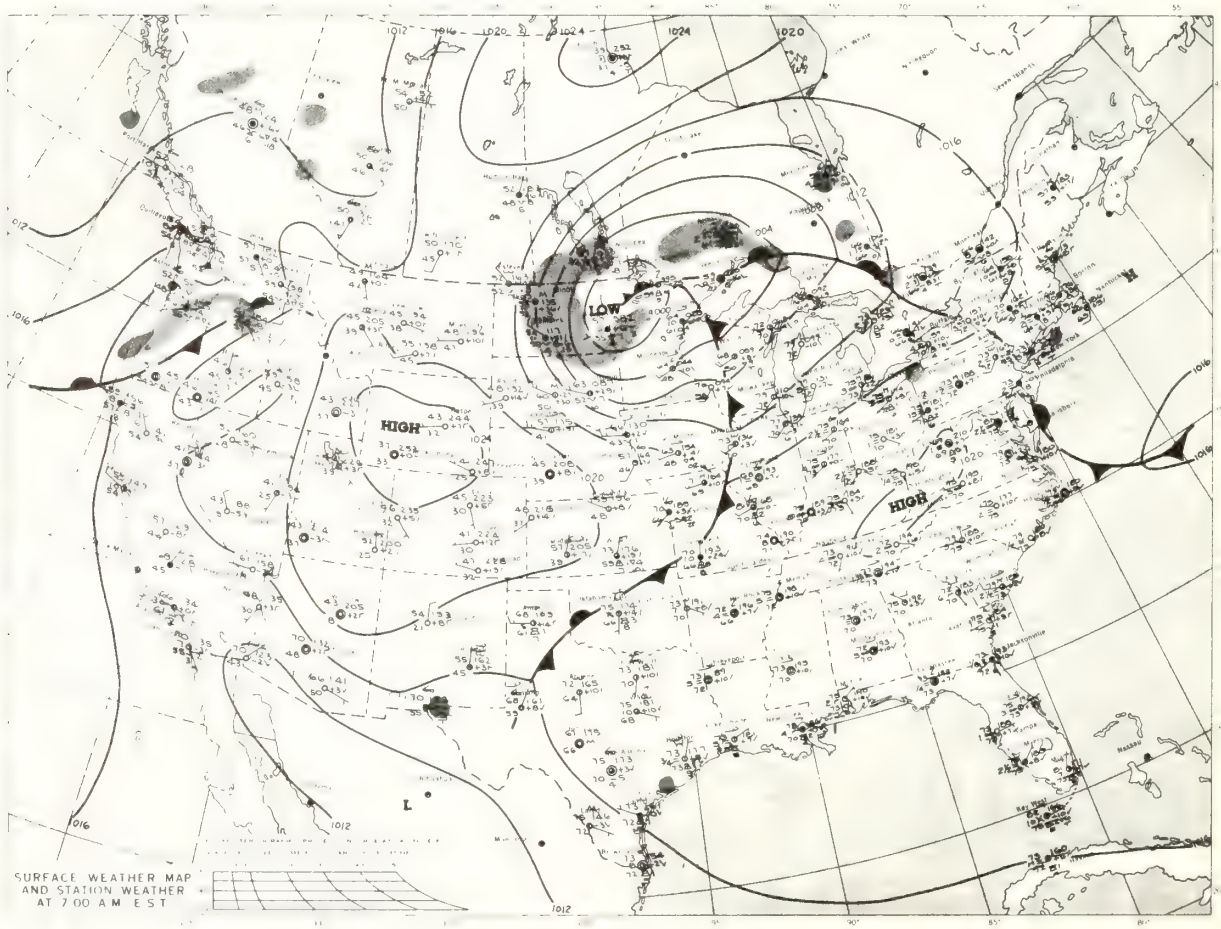

Figure 8.–*Daily surface weather map for 0500 local, August 24, 1968.*

Table 2.–*Weather observations for Los Angeles Basin and area, August 24, 1968*

Time (P.d.s.t.)	Sky condition	Visibility	Temperature	Dew-point	Wind direction	Wind speed	Relative humidity
		Miles	*°F.*	*°F.*		*M.p.h.*	*Pct*
			LOS ANGELES				
0700	High broken	1	66	62	E	4	87
0800	Obscuration	0	63	63	SSE	5	100
0900	Obscuration	1/16	64	64	ESE	5	100
1000	Partial obscuration	1	72	65		(1)	80
1100	Partial obscuration	2	76	65	SW	5	68
1200	Partial obscuration	3	77	64	SW	9	65
1300	High scattered	4	75	63	SW	12	66
1400	Clear	4	77	64	WSW	9	64
			LONG BEACH				
0700	Obscuration	1/8	65	64	SE	6	98
0800	Obscuration	1/2	65	64	SSE	5	98
0900	Scattered/high scattered	2-1/2	68	63	SSW	4	85
1000	High thin scattered	3	74	63	ESE	4	70
1100	High thin scattered	5	79	61	SSW	6	53
1200	High scattered	8	83	53	SSW	8	35
1300	High scattered	8	86	49	SSW	6	28
1400	High scattered	10	87	50	S	10	28
			ONTARIO				
0700	High scattered	15	64	41	N	1	43
0800	High overcast	6	70	43	SE	1	37
0900	High broken	6	77	43	NNW	1	30
1000	High broken	6	82	42	SW	2	25
1100	High scattered	8	87	42	S	7	21
1200	High scattered	8	90	44	WSW	5	20
1300	High scattered	15	91	47	SE	6	22
1400	High scattered	15	94	47	SSW	8	20

[1]Calm.

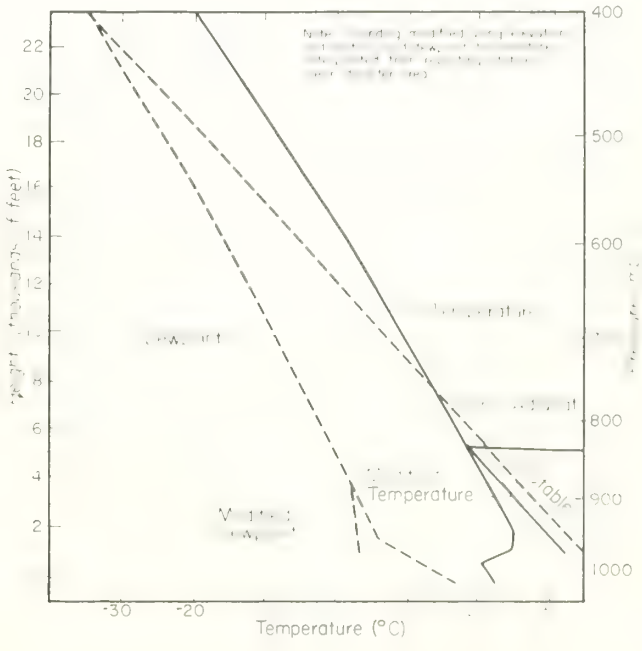

Figure 9.–*Radiosonde observation at Los Angeles, 1300 local, August 24, 1968.*

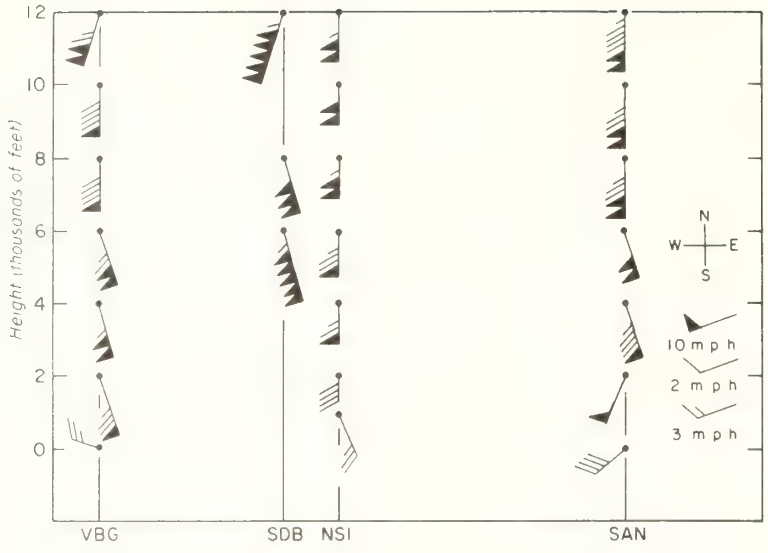

Figure 10.—*Cross section of winds at 1100 P.d.s.t. on August 24, 1968 over Vandenburg AFB (VBG). Sandberg, California (SDB), San Nicholos Island (NSI), and San Diego (SAN).*

temperature at Azusa at 1100 was 89°F. and at 1200 was 94°F. A conservative estimate of 90°F. for the surface temperature at the fire and a similarly conservative estimate of dewpoint were used to construct the sounding. The sounding shows that little energy would be necessary to overcome the static stability in the fire area. In other words, existing atmospheric conditions were such that strong convection could easily be established by an outside influence such as heat source or wind movement.

Upper winds over southern California were southerly and relatively strong on August 24 *(fig. 10).* Streamline analyses of data from Los Angeles, Riverside, and San Bernardino County Air Pollution Control District stations and the Environmental Science Services Administration, Weather Bureau stations were made *(fig. 11).* The surface windflow at 0800 on August 24 was characterized by downcanyon and offshore flow *(fig. 12).* The only evidence of onshore flow (sea breeze) was in the Long Beach area of the Basin. By 0900 we see the sea breeze was evident all along the coast and downslope winds were decreasing as shown by the shift from northerly to easterly winds along the foothills *(fig. 13).* The sea breeze had reached the Azusa area for the first time on the 24th by 1000 *(fig. 14).*, retreated before 1100 as indicated by the east winds *(fig. 15),* then advanced into the Azusa area by the next hour, 1200, as shown by the flow pattern at that time *(fig. 16).* The sea breeze was very strong in all areas by 1200 and was becoming stronger by 1300 *(fig. 17).*

The surge of the sea breeze into Azusa as shown on the 1000 chart was probably onshore flow aloft surfacing because of instability and convective mixing due to surface warming. But this instability and warming was not sufficient to hold the sea breeze in the Azusa area so it retreated. It returned to stay when there was sufficient surface heating.

The closest reporting station to the disaster area was the Azusa Air Pollution Sampling Station located 2.7 miles to the west-southwest. The wind direction and speed record for that station shows that the sea breeze that was at Azusa at 1000 retreated at 1010 with the wind shift from southwesterly to easterly *(fig. 18).* At 1120 the winds shifted again to southwesterly as the sea breeze arrived again in the Azusa area. This same surge of the sea breeze most likely penetrated also into the disaster area and possibly caused the sudden change of wind direction and an increase of windspeed at the exact time (1124) the fire whirl developed. (The times on the record are P.s.t. so one hour must be added for P.d.s.t.)

Fire Weather Conditions

An analysis of the Fire Load Index (FLI) was made for August 21 through August 24. The FLI is an indication of the fire danger and is a function of fuel moisture, temperature, humidity, and windspeed. Observations contributing to FLI from four nearby stations are given in table 3. The FLI was low on the 21st and 22nd with Duarte and Eaton Canyons reporting 6 on both days; but the Santa Ana condition occurred on the 23rd, with a sharp rise in temperature and a drop in relative humidity. This caused a large rise in FLI. The Santa Ana condition was gone by the 24th; however, the effects were still

Table 3.–*Fire weather observations before and during the Canyon Fire*

Date (1968)	Dry bulb	Wet bulb	Dew-point	Rel. humidity	Stick moisture	Wind direction	Wind speed	Fire load index
	°F.	°F.	°F.	Pct.	Pct.		M.p.h.	
	PADUA HILLS, ELEVATION 1,810 FEET, 1330 P.D.S.T.							
8/21	75	57	43	31	9.0	SW	10	10
8/22	77	58	43	30	9.0	SW	12	14
8/23	93	58	20	7	6.0	S	8	18
8/24	–	–	–	–	–	–	–	–
	EATON CANYON, ELEVATION 975 FEET, 1330 P.D.S.T.							
8/21	77	58	43	30	7.0	SE	6	6
8/22	82	64	53	37	7.0	S	6	6
8/23	95	62	35	12	5.0	SE	10	31
8/24	94	63	40	15	5.0	E	8	20
	DUARTE, ELEVATION 580 FEET, 1430 P.D.S.T.							
8/21	79	60	46	32	6.0	SW	4	6
8/22	82	62	49	31	7.0	SW	5	6
8/23	98	64	38	13	[1]4.5	SE	10	[1]31
8/24	96	62	34	11	4.0	SW	7	26
	IRVINE LAKE, ELEVATION 970 FEET, 1430 P.D.S.T.							
8/21	73	58	47	40	9.0	SW	12	10
8/22	76	63	55	49	9.0	SW	5	3
8/23	94	60	28	10	5.5	W	10	29
8/24	86	64	50	29	5.0	W	9	10

[1]Estimated

Table 4.–*1968 precipitation data for stations near the disaster area*[1]

Month, day	Glendora West	Azusa City Park	Rogers Canyon
	Inches		
January	1.48	1.35	1.39
February	1.71	.62	1.53
March	3.72	4.16	3.97
April	.92	.68	1.09
May	.06	(2)	.31
June	.18	.10	.09
July	.03	.02	(2)
August 7th	.01	.20	.10
17th	.02	(2)	.03
20th	(2)		
Total[3]	8.13	7.13	8.51

[1]Glendora West is 1.5 miles southeast of the disaster area; Azusa Park is 1.8 miles southwest; and Rogers Canyon is 1.6 miles west-northwest.

[2]Trace.

[3]To August 25, 1968.

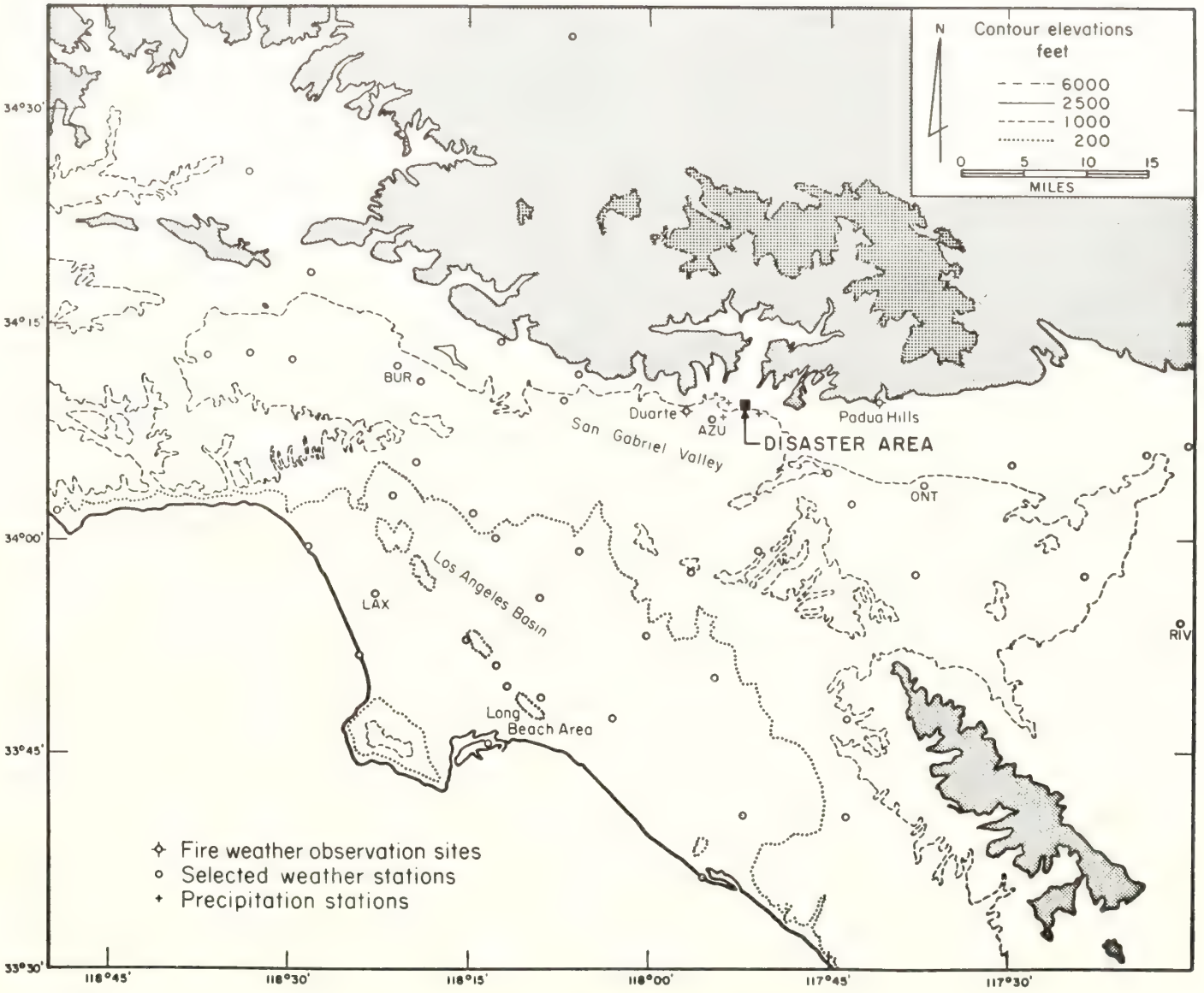

Figure 11.—*Location of data stations and disaster area.*

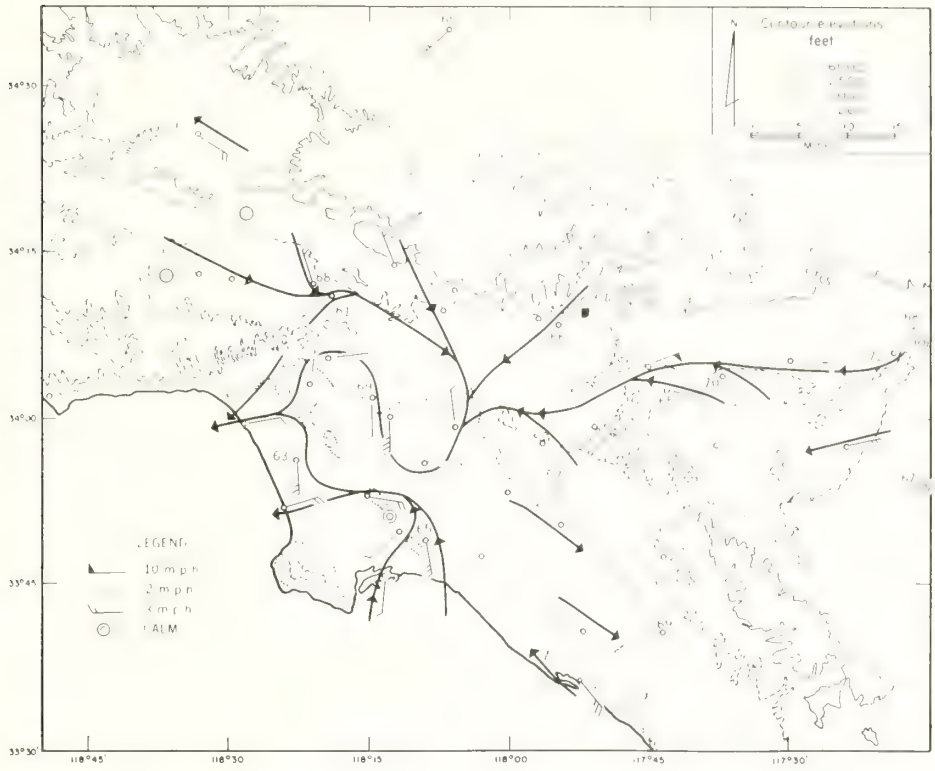

Figure 12.—*Streamline analysis for Los Angeles Basin at 0800 local, August 24, 1968. Temperatures are plotted above the station.*

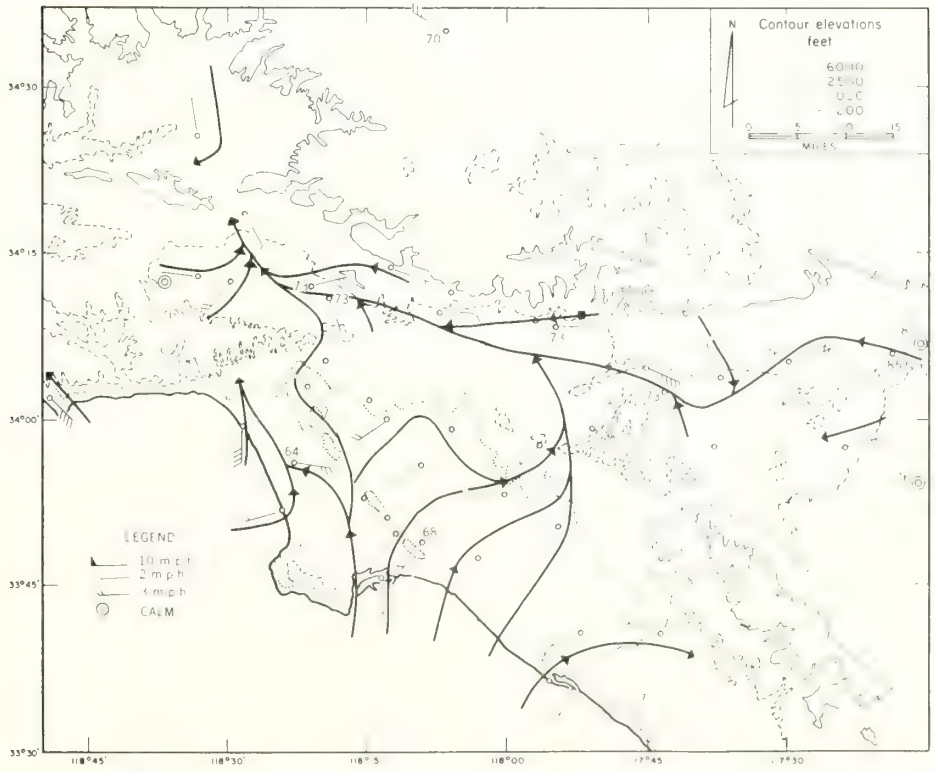

Figure 13.—*Streamline analysis for Los Angeles Basin at 0900 local, August 24, 1968. Temperatures are plotted above the station.*

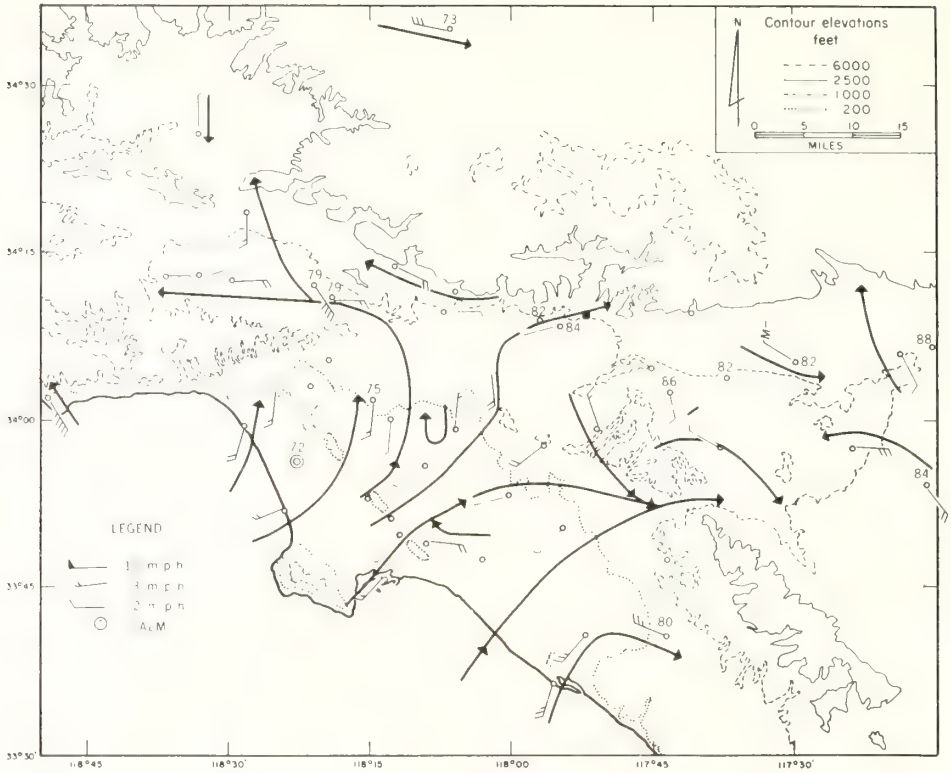

Figure 14.—*Streamline analysis for Los Angeles Basin at 1000 local, August 24, 1968. Temperatures are plotted above the station.*

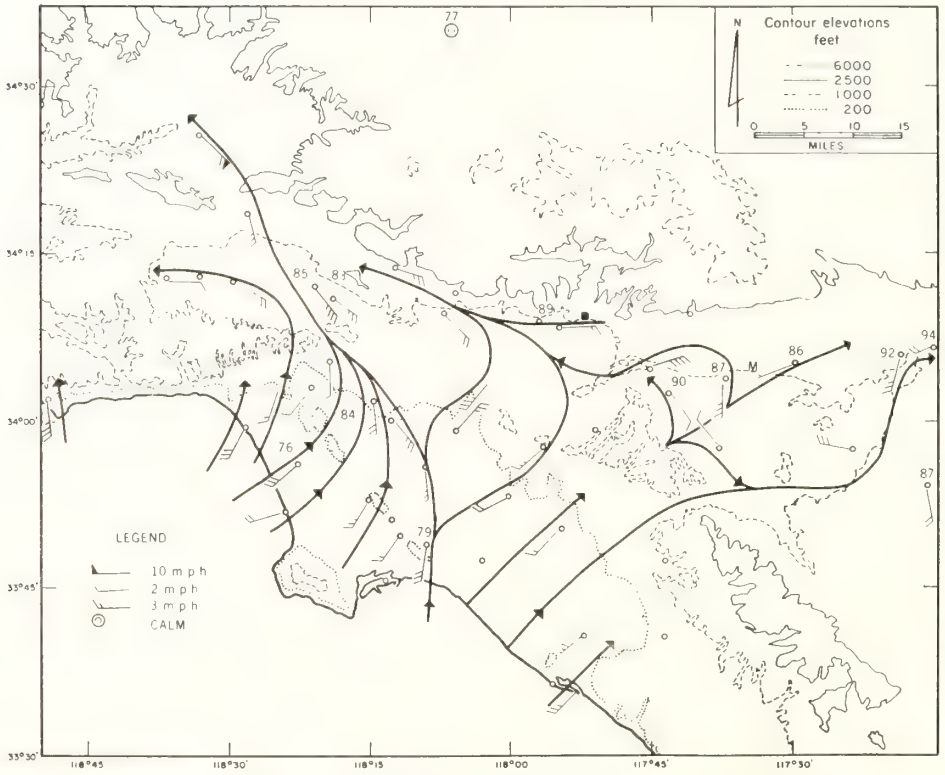

Figure 15.—*Streamline analysis for Los Angeles Basin at 1100 local, August 24, 1968. Temperatures are plotted above the station.*

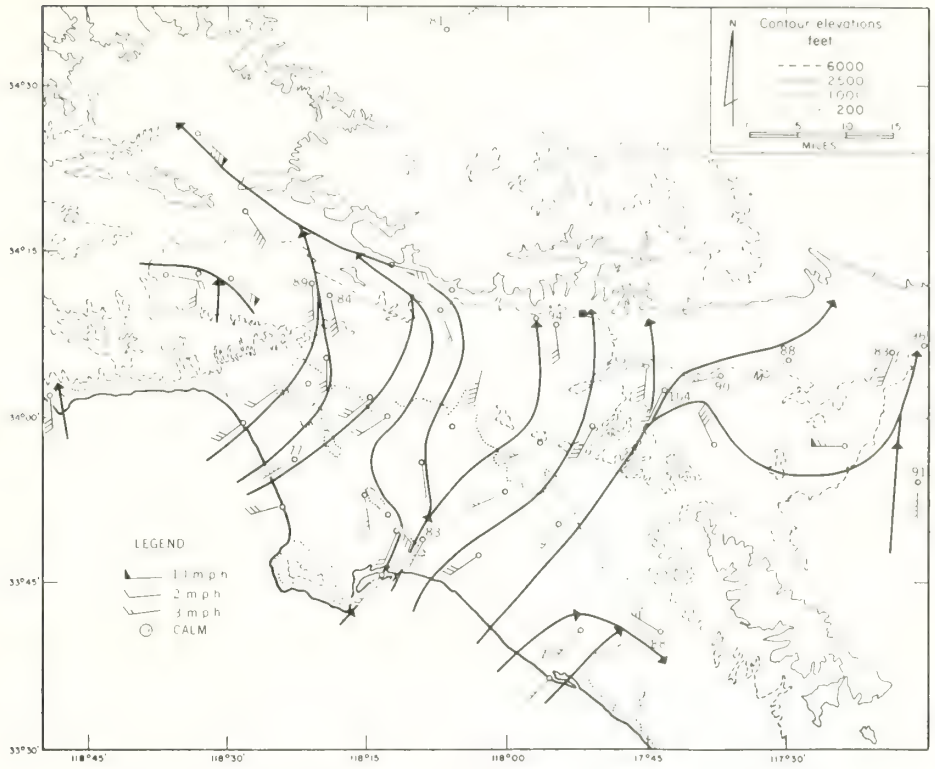

Figure 16.—*Streamline analysis for Los Angeles Basin at 1200 local, August 24, 1968. Temperatures are plotted above the station.*

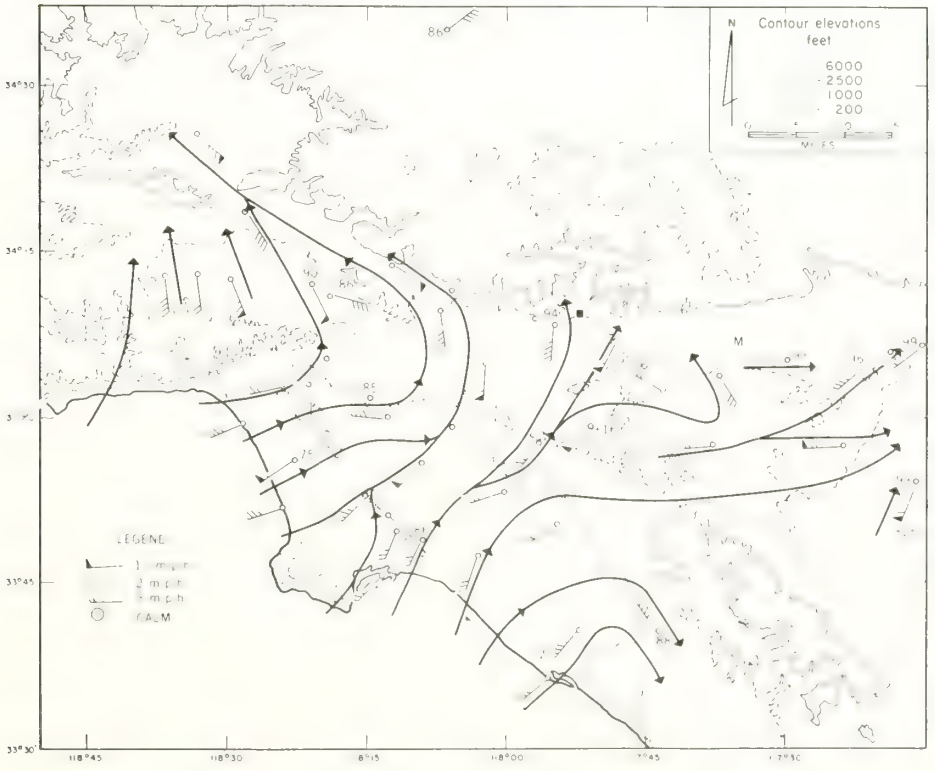

Figure 17.—*Streamline analysis for Los Angeles Basin at 1300 local, August 24, 1968. Temperatures are plotted above the station.*

felt in the disaster area as evidenced by the observations at Duarte, only 4 miles to the west.

Lack of precipitation contributed strongly, of course, to the high FLI. The last rain occurred in the area on August 17 *(table 4)*, but this was very light. The last significant rainfall occurred in April.

FUELS ANALYSIS

The driving force of any wildland fire is of course the energy provided by the particular combination of fuels present. Therefore, characteristics such as fuel size, loading, moisture content, heating value, and fuel bed compactness are of prime importance in analyzing fire behavior.

Fuel Types

The chief chaparral fuels at the disaster site on the Canyon Fire were sumac, scrub oak, chamise, and sagebrush, but a few sycamores and introduced shrubs and trees which apparently originated from landscape plantings in nearby residential areas, were scattered throughout. A dense stand of grass and other herbaceous vegetation grew in association with chamise, and sagebrush in the more open places.

The last major fire in this general area was in 1919. Local residents indicated, however, that some areas in the Canyon Fire had not been burned for 70 years or more. The disaster site was probably one of these. Because of the age of the cover, many years of low rainfall, and smog damage, there was a heavy accumulation of litter and a large amount of dead material in the standing fuel. Unburned fuel *(figs. 19, 20)* near

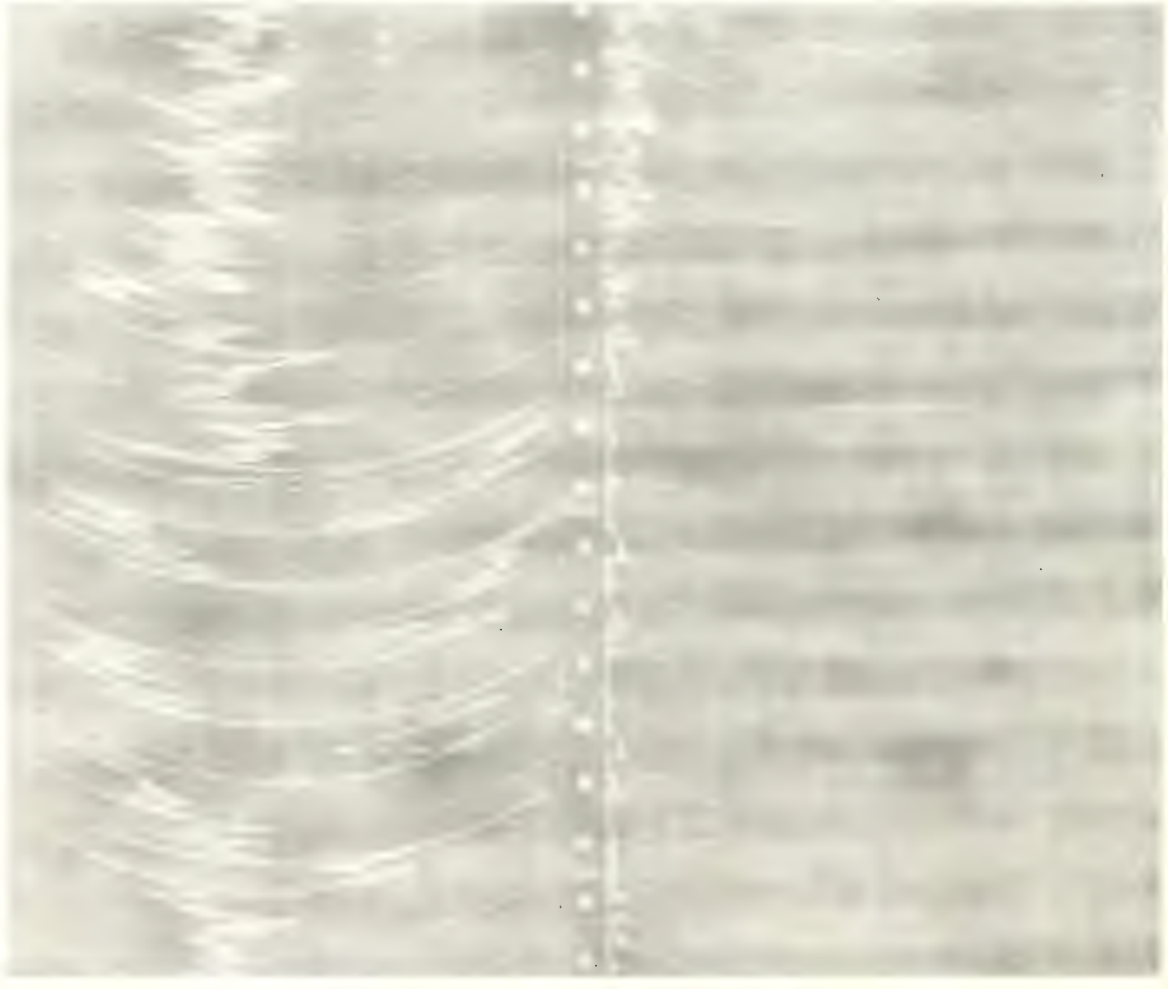

Figure 18.—*Wind speed and direction record for the Azusa Air Pollution Sampling Station. The times are P.s.t.*

Figure 19.—*Characteristic fuel of the fire accident area.*

the fire area is believed typical of fuel conditions at the disaster site.

Fuel Moisture

The moisture content of the fuel strongly influences the speed with which the fuel burns and hence the rate of release of its potential thermal energy. Fuel moisture samples taken from living plants near the fire area a few hours after the accident indicated sagebrush leaves had a moisture content of 131 percent, scrub oak leaves 79 percent, and chamise leaves 63 percent. These moisture contents are about normal for the season of the year and are low enough so that the foliage and small limbs can contribute substantially to the heat production of the burning fuel.

The moisture content of the dead fuels is highly dependent on the relative humidity and fuel temperature. Samples of scrub oak deadwood had a moisture content of 5.1 percent. This value is consistent with the relative humidity and temperature for August 24, and very close to the value determined at nearby fire weather stations. Although not extremely low, it is well within the range where fuels will burn hot and fast.

Fuel Loading

Except under very extreme conditions chaparral fuels seldom burn up completely. The smaller dead and live stems, foliage, and surface fuels burn first, creating the thermal pulse peak and the long flames

Figure 20.—*Heavy ground fuel typical of fire accident area.*

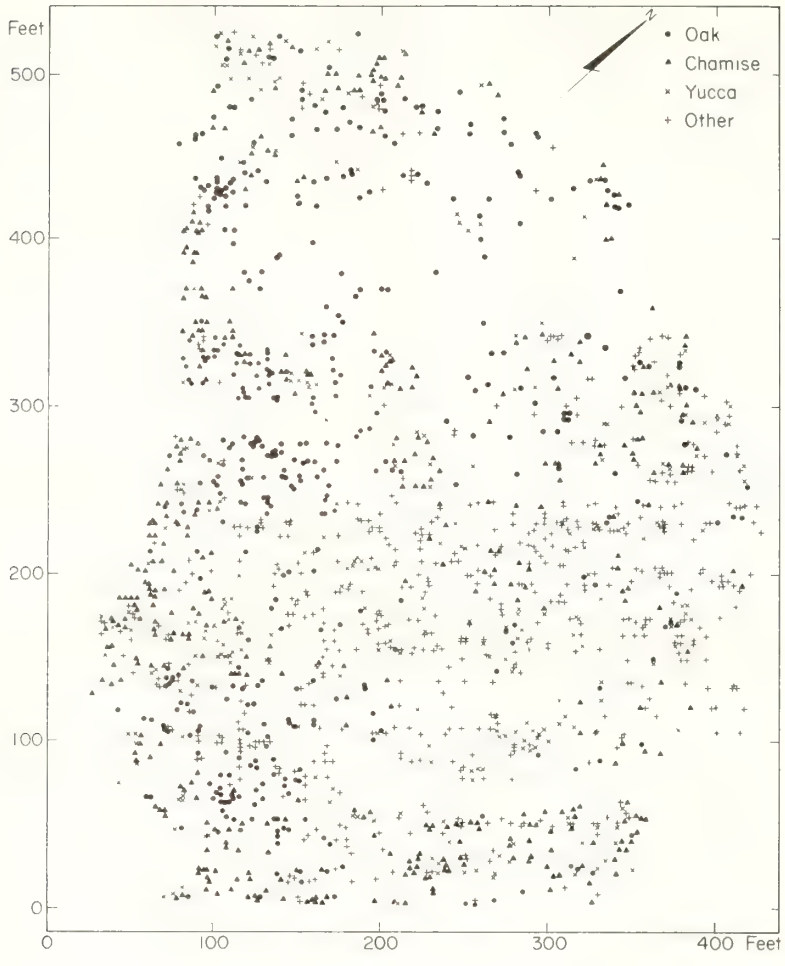

Figure 21.–*Fuel remnant location map for accident ravine. Map shows plant locations, not area.*

that carry the fire into unburned fuel. The larger fuels burn later or not at all. To provide an estimate of the fuels that actually burned, the ravine in which the men were trapped was divided into 25-foot-wide horizontal strips. The location of each plant within each strip was plotted on a map and an estimate was made of the proportion of the plant that had burned. The resulting map also showed the vegetation density *(fig. 21)*.

For the predominant species, typical fuel loadings and proportion of dead material for fuels of the height and density of those in the fire area were:[3]

Species:	Lb./sq. ft.	Percent dead
Scrub Oak	1.06	20
Sumac	1.06	20
Sagebrush	.28	50
Chamise	.28	35
Grass	.18	100

[3]Derived from Operation Firestop data.

Under the scrub oak and sumac the ground fuel and litter was estimated at 1.01 lb./sq. ft., and under the chamise and sagebrush, 0.26 lb./sq. ft. In the open areas between shrub fuel patches the herbaceous fuel loading was estimated to be 0.18 lb./sq. ft.

Fuel Heating Values

The heating values of woody material in chaparral fuels do not vary greatly among species. The heating value of the foliage, however, is usually somewhat higher than that of the wood. Table 5 lists typical values for the predominant species in the fire area.

Table 5.–*Heating values of selected chaparral species*

Species	Wood	Foliage
	B.T.U./lb.	
Scrub oak	8,050	8,766
Sumac	8,228	8,873
Sagebrush	8,213	9,652
Chamise	8,411	9,431

Heat Production

The fuel that contributed directly to the fire run that killed the Camp 4-4 crew was in areas B and C *(fig. 22)*. Area B was covered principally with scrub oak and sumac and a deep layer of litter. Grass grew in the more open areas. Chief fuel in area C was chamise and sagebrush along with a dense stand of grass and other herbaceous vegetation. Surface area of B was 22,326 sq. ft.; of C, 1,586 sq. ft.

Total fuel that burned in area B is estimated at 30,810 lb. and in area C at 1,460 lb. Total fuel in the two areas was thus 32,270 lb., or about 1.35 lb./sq. ft. Assuming a heating value of 8,300 B.t.u./lb., the total heat production for the two areas would be about 261,841,000 B.t.u., or 11,201 B.t.u./ sq. ft. Burning time for the fuels would be 4 to 5 minutes. However, about 65 percent of the fuel could be expected to burn in the first 30 seconds. This would give a heat production rate of 14,561 B.t.u./sq. ft. per minute. With fuels burning at this rate, combustion zone temperatures in the order of 2500°F. would be likely.

FIRE BEHAVIOR

In the earlier section on weather, we had reported that wind speeds during the morning of August 24 were variable. In the disaster area they were very light—estimated at 2 to 4 miles per hour by firemen at the site. Under these conditions the fire behavior was almost entirely controlled by the topography.

Topography-Dominated Fire Behavior

Topography-dominated fire behavior has certain well defined characteristics. Where the fire is backing down a steep slope, as it was on Glendora Ridge, the fire spread is frequently slow and intermittent. The fire moves along one fuel element to the next and initially may burn only the more compact fuels near the ground surface. In steep topography, fire spread is speeded by burning material rolling down the slopes, igniting other fuel as it goes. Flying firebrands from flareups may also scatter fire over a wider area.

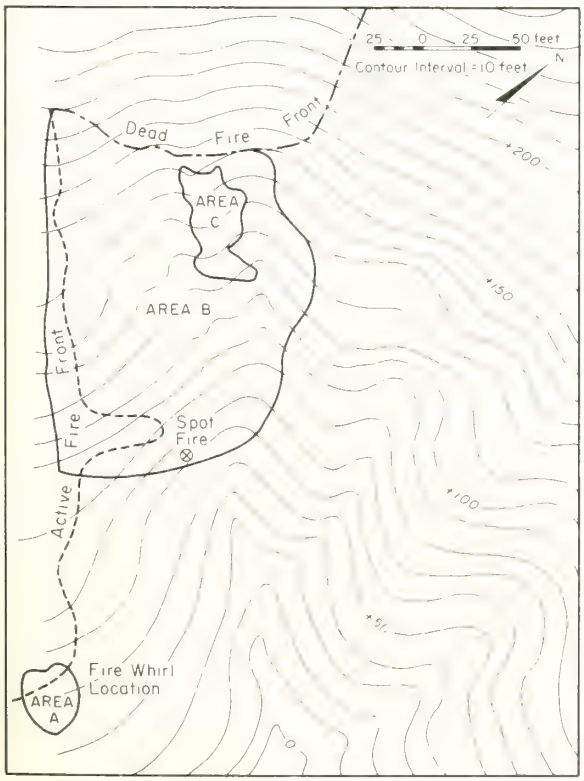

Figure 22,—*Topographic map of accident ravine.*

In steep V-shaped ravines the fire tends to progress most rapidly down the bottom of the ravine since rolling material tends to collect there. Once the fire becomes established in the bottom of the ravine, fuel then becomes available upslope from the fire along the ravine sides, and a series of fire runs up the slope and up the ravine can develop. The fire front in a ravine then soon assumes a V shape with the apex of the V pointed downslope. The upslope fire runs often carry over the rim of the ravine and provide a source of rolling firebrands to spread fire into the bottom of the next ravine. These hot fire runs also provide the necessary convection and turbulence to carry firebrands into unburned fuel.

When the fire front can move laterally as well as downslope, the fire runs tend to become longer and more intense. As the fire progresses down one ravine the probability becomes greater that a fire run up the ravine side will establish fire in an adjacent unburned ravine. Then extensive areas of fuel above the fire become available and a long fire run is possible.

During the daytime natural thermal convection plays an important role in the behavior of a fire, particularly for slopes with a southerly aspect. Because of unequal solar heating, convection currents are stronger in the ravines than over the slope as a whole. These air currents aid in the early development of the fire in the ravine bottom. Once a fire run starts, the added heat from the fire increases the

natural convective flow and the fire is pushed faster and faster as its flaming area increases. Because of the slope and convective air flow, the flames are held close to the fuel and there is efficient flame contact and fuel preheating. When the fire reaches the top of the ravine wall or the head of the ravine, the convective flow slackens and progress slows until the fire works its way into a favorable position of fuel and topography for another run.

Between runs, progress of a fire down the slope is often very slow. Because of the upslope thermal currents the flames are bent away from unburned fuel. The thermal currents also tend to cool the standing fuels and prevent their ignition by radiated heat. Downward movement of the fire is thus primarily in the surface fuels, and the fire may move for a considerable distance downslope without igniting the standing fuel. However, there is usually a delicate balance here, particularly in chaparral fuels. A gust of wind, a concentration of surface fuel, or a low-growing shrub can result in one shrub "crowning out." When this happens, adjacent shrubs are immediately in the flame zone and a fire run or "flareup" is triggered. In dry fuels, on steep slopes, and under strong solar heating these flareups can develop very quickly and move with great speed. Rates of spread of 6 to 10 ft./sec. are common and spread rates as great as 100 ft./sec. for short distances under extreme conditions have been noted.

Fire Behavior in Disaster Area

The fire run that trapped the Camp 4-4 crew was similar to numerous runs that had occurred on Glendora Ridge previous to the accident. By 0830, fire in the adjacent ravine had already begun to move downslope in the typical V-shaped pattern. Fire had also slopped over the rim at the upper edge of the ravine in which the crew was working. Additional fire runs up the wall of the adjacent ravine increased the amount of fire at the rim of the accident ravine. Water drops by a helicopter slowed the spread of the fire but failed to check it entirely. By 1100 the fire had burned over the rim for a considerable distance down from the head of the ravine and, at the lower end of the slopover, was burning briskly and moving down into the ravine *(figs. 22, 23)*. At about 1124 a patch of sumac and scrub oak in this area crowned out suddenly. A fire whirl quickly formed over the hotly burning brush patch *(fig. 22, 24)*. It appears likely that a firebrand from this whirl moved downslope and established fire well down into the ravine and below the crew *(figs. 22 and 25)*. This fire crowned immediately and ran up the ravine and over the crew *(fig. 26)*. Probably not more than a minute elapsed from the time the fire whirl developed and the time fire became established below the Camp 4-4 crew. It is likely the fire run that trapped and killed the crew reached the head of the ravine in 30 seconds or less.

Figure 23.–*Fire front at about 1100 hours on August 24.*

Figure 24.—*Fire whirl believed responsible for establishing fire below crew.*

Figure 25.—*Spot fire (upper right) below crew location. Note remnants of fire whirl still visible at upper left.*

Because of the steep slopes and strong convective currents, the flames were held close to the ground so that the crew was subjected to maximum temperatures. It is likely that the fire front was preceded by a wave of hot combustion products high in carbon monoxide and carbon dioxide and low in oxygen.

The chief difference between the fire runs that trapped the crew and previous fire runs on the Canyon Fire was the appearance of the fire whirl. Fire whirls had not been observed previously by the firefighters on the line. Although fire whirls frequently appear on the lee side of ridge tops, their development in this area is usually restricted to

Figure 26.—*Beginning of fire run that trapped crew. Crew location is to left and above point of highest flame.*

conditions of moderate air flow or to areas where natural eddies or vorticity appears. It thus appears probable that the fire whirl was caused by a sudden and local increase in air flow. The increase in fire activity all along the slopover area tends to bear this out. Increasing air instability resulting from warming of the surface air layer as the day progressed also probably aided in the whirl development.

The increase in speed of the local air flow may have resulted from the sea-breeze front reaching the fire area. It also may have been caused by the turbulence created by the low-level passage of an air tanker through the area just before the fire flareup. Both of these potential causes may have combined to increase the air flow and turbulence. Data available do not permit us to pinpoint the exact cause.

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LOCAL AND REGIONAL VARIATION IN THE MONOTERPENES OF PONDEROSA PINE WOOD OLEORESIN

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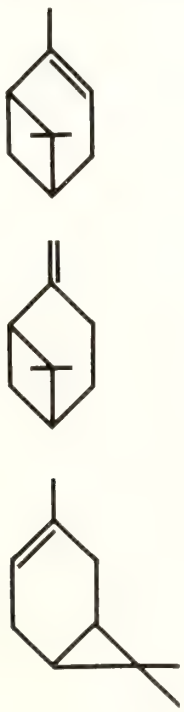

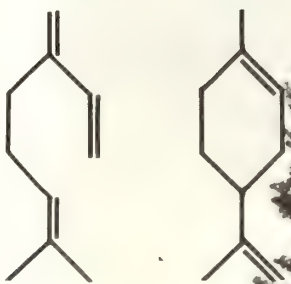

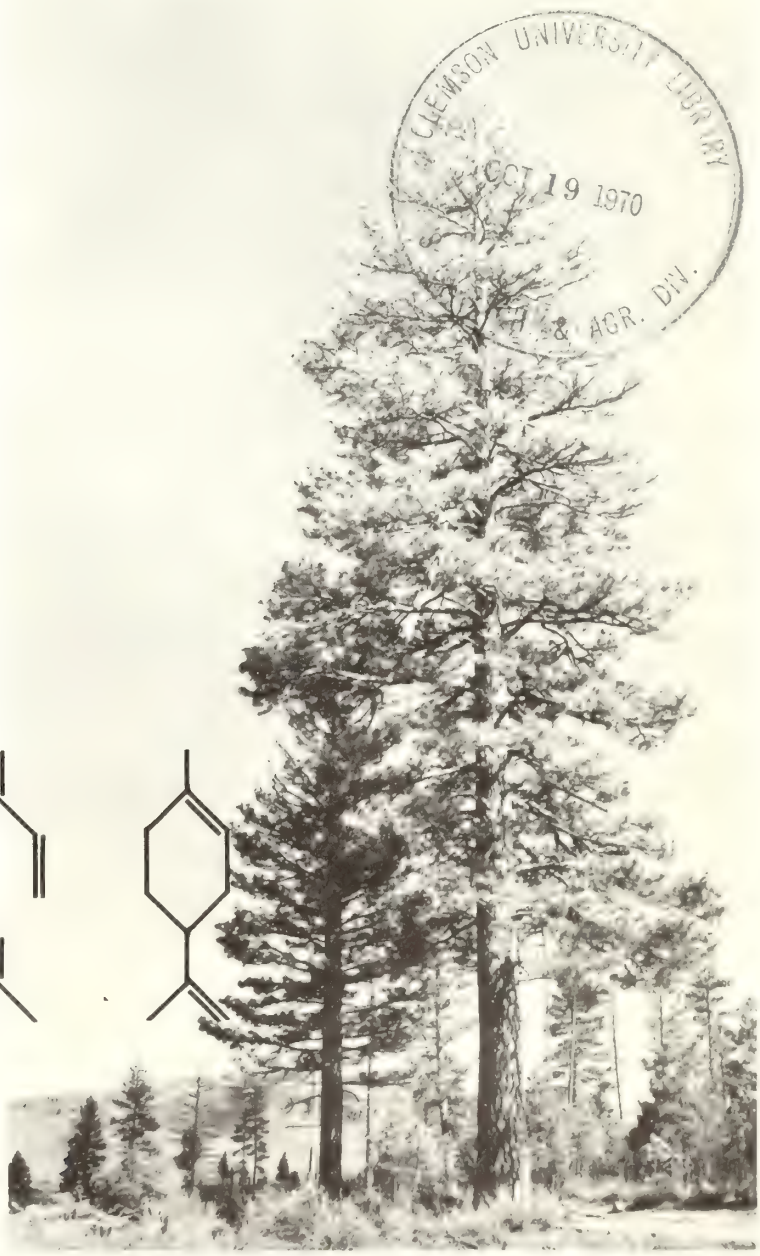

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The Authors

RICHARD H. SMITH is in charge of this Station's research on the biology, ecology, and control of destructive forest insects, with headquarters in Berkeley. He holds B.S. (1942) and M.S. (1947) degrees from New York State University, College of Forestry, and a Ph.D. degree (1961) from the University of California, Berkeley. **ROBERT L. PELOQUIN** was a graduate in biology at the time of the study reported in this paper. He earned a bachelor's degree (1962) in botany at Purdue University, and a master's degree (1964) in biology, at Stanford University. He is now an instructor of biology at Purdue University at Calumet, Hammond, Indiana. **PETER A. PASSOF** collected data for this paper while employed at the Station's Institute of Forest Genetics, Placerville, Calif. He earned a bachelor's degree (1963) at Humboldt State College, Arcata, Calif., and a master's degree (1964) at the Yale University School of Forestry. He is now stationed in Ukiah, Calif., as forestry farm advisor with the University of California Agricultural Extension Service for Mendocino County.

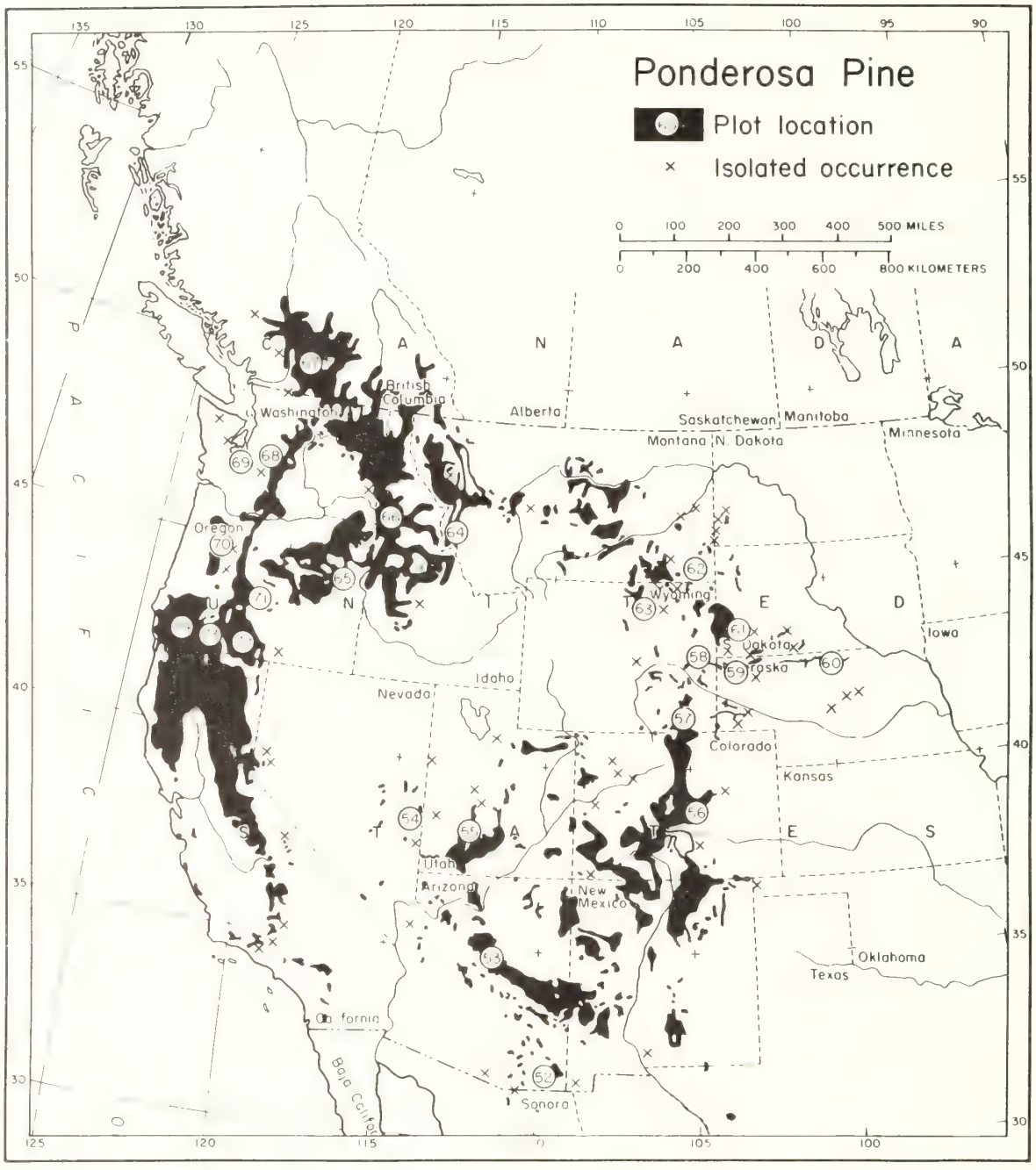

Figure 1.—*Distribution of Pinus ponderosa Laws. (from Critchfield and Little 1966) and location outside California of source used in monoterpene studies.*

Ponderosa pine *(Pinus ponderosa* Laws.*)* is one of the most abundant, economically important, and widely distributed pines in North America. Its range extends from British Columbia to Mexico and from Nebraska to the Pacific Ocean *(fig. 1).* Quite variable, it is often subdivided into var. *scopulorum,* found on the east side of the northern Rocky Mountains and throughout the central and southern Rockies; var. *arizonica,* found only in southern Arizona and northern Mexico; and var. *ponderosa,* found on the remainder of the range. Var. *ponderosa* generally grows west of a line from the southeastern tip of Alberta to the southwestern tip of California; the other two varieties grow east of that line. But neither the existing definition nor distribution of these varieties is fully satisfactory.

Mirov (1961) found considerable regional variation in the turpentine composition of the wood oleoresin of ponderosa pine. His data were limited to small numbers of trees. And he had to combine resin from several trees to obtain the quantity needed for chemical analysis. Individual tree variation was obscured by the combining process, and he was unable to detect trace amounts of constituents.

Two recent studies have been made of ponderosa pine xylem monoterpene variation. Smith (1964) found large variations in the monoterpene composition within local populations of trees. Peloquin[1] found large regional variations, as did Mirov, and proposed eight types. He also found considerable variation within local populations in a region. Within a tree Smith (1964, 1968) found no variation due to season, method and place of sampling, and time and method of analysis.

This paper reports much of the data in the papers by Peloquin[1] and Smith (1964) and enlarges the scope of the study to include 927 trees. These data were gathered over a period of 3 years from samples taken in natural stands and from trees growing in plantations at the Institute of Forest Genetics (IFG), Placerville, Calif., from seed collected at the designated sites shown in figures 1 and 2. Much of the seed was collected from only a few trees—often less than three—at a locality. Variation could be reduced by this limited parentage. However, Peloquin[2] found nearly as much variation among siblings as among nonsiblings. We assumed that the place of germination of the seed and growth of the tree had no major effect on the monoterpene composition of ponderosa pine.

This study was made for three reasons: (1) Trees of varying composition were needed for further study and testing of the resistance of ponderosa pine to the western pine beetle *(Dendroctonus brevicomis* LeConte*);* (2) the range of ponderosa pine is much greater than that of the beetle; studies of regional variation of monoterpenes might shed some light on this noncoincidence of ranges; and (3) the definition and distribution of ponderosa pine and its varieties could be clarified by data on monoterpenes.

PROCEDURES

The procedure used to collect and process the samples has been previously described (Peloquin[3]; Smith 1964). Essentially, a pentane preparation was made by adding an approximately equal volume of pentane to a sample of the freshly collected resin; in some cases a molecular distillate of the fresh resin was obtained at 40°C. The analysis of both kinds of preparation of the sample gave identical results. All preparations were held in tightly sealed vials at 35°F.

[1]Peloquin, R. L. *Geographic variations of the monoterpenes of Pinus ponderosa.* 1964. (Unpubl. master's thesis on file Stanford Univ., Palo Alto, Calif.)
[2]*Op. cit.*
[3]*Op. cit.*

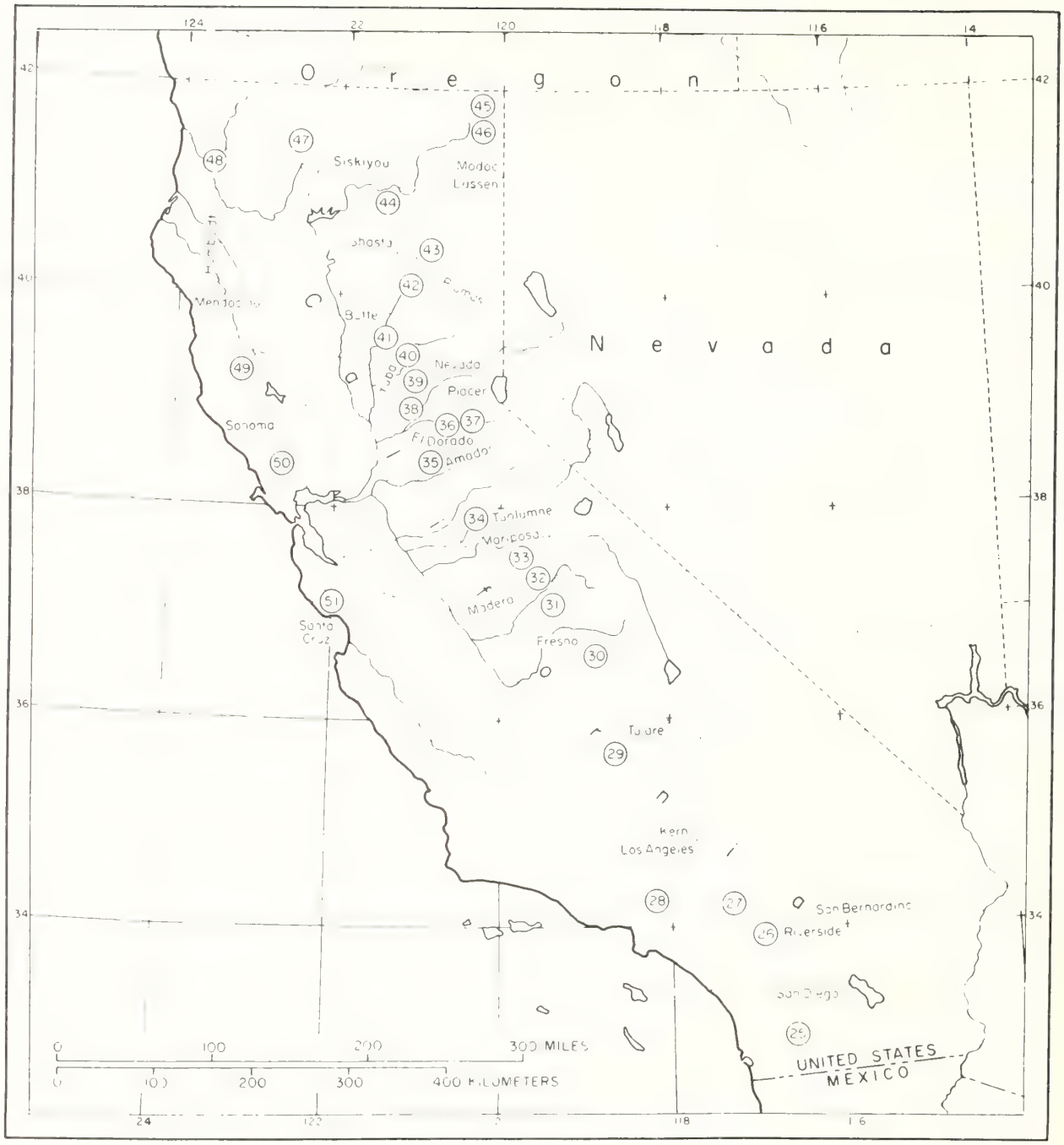

Figure 2.—*Location of sources in California of trees used in the study of the monoterpenes of ponderosa pine wood oleoresin.*

Samples were analyzed on the same gas chromatograph, using a thermal conductivity detector. The column was 8 feet by 1/8-inch stainless steel. The solid support was Chromosorb W A/W at 60/80 or 80/100 mesh; the liquid support was 7-1/2 or 10 percent β,β' oxydipropionitrile. Operational conditions were 130 to 140°C. on the injector, 55 to 65°C. on the column, and 145 to 155°C. on the

detector. There were 200 ma. on the detector and 30 to 60 ml. of helium per minute. Sample size varied from 0.2 to 1.0 μ l. Variations in these working parameters did not affect the analyses.

Qualitative determinations were made by comparing relative retention times with known chemicals and mixtures of known chemicals and by introducing these standards into the sample. These determinations were checked on two alternate columns: LAC-446 at 90°C. and Apiezon L at 110°C. Quantitative determinations were based on normalization of peak areas, as measured by a disc integrator.

Six limitations of the data should be emphasized: (1) All data apply to trees greater than 35 years old; (2) all resin was from the xylem; therefore, the data probably do not apply to other resin systems, such as needle, cortex, etc.; (3) all data apply only to normalized monoterpene components; (4) the data do not consider differences which might exist between trees in the proportion of the monoterpenes to the total resin; (5) the number of trees from a source varied considerably; some sources are represented by as few as two trees; (6) very small amounts of heptane might be masked by the solvent peak; however, measurable amounts can be found with the columns used.

RESULTS

Variations in Major Components

The five major monoterpene components in this analysis were: α-pinene, β-pinene, 3-carene, myrcene, and limonene. The minor components were considered separately.

Elevation

Ponderosa pine grows from near sea level to about 6,500 feet elevation in the central Sierra Nevada. The effect of elevation was studied by using 10 sources in the plantations at IFG and three sources from field locations which together comprise a transect. This transect extended from 1,800 to 6,700 feet. All sources except the one at 6,700 feet were within 10 miles of the South Fork of the American River in El Dorado County, Calif.; the 6,700-foot source was northeast of Lake Tahoe, about 30 miles from the transect line.

The mean and range for the five major monoterpene components varied considerably *(fig. 3A)*. No apparent elevational trend was evident. There appeared to be no greater difference among the three field sources (Nos. 1, 5, 8) than there was among the 10 plantation sources. The three plots (Nos. 8, 9, 10) at the same elevation (2,700 feet) showed as much variation and range as did the plots at different elevations.

Eleven field plots were set up at 3,500 $\pm$ 300 feet elevation, all within a radius of 3 miles. The site lies near the midelevation of ponderosa pine in this region, near plot 36 *(fig. 2)*. Again, there was nearly as much range and variation among single-elevation plots *(fig. 3B)* as among those at differing elevations.

Thus, elevation appears to have little or no effect on monoterpene composition—at least in the central Sierra Nevada. Any variation attributable to elevation appears to be masked by much larger local variations.

California

All but seven counties in California with ponderosa pine were sampled either by plantation plots at IFG or by natural plots *(fig. 2)*. The mean and range for all sources *(fig. 4)* are arranged in the numerical sequence used in figure 2. The trees in plot No. 36 were 30 to 40 years old; those in plot No. 37 were 200 to 400 years. The two plots differed only slightly in their monoterpene composition. Plots Nos. 45 and 46 represented natural and plantation plots; the first was a plantation plot of eight trees, the second a natural plot of 72 trees.

Neither the kind nor size of plot changed the average values appreciably, though an increase in the number of trees increased the minimum-maximum range. With more intensive sampling, all localities might be found to have a greater range of values.

California appears to have at least two types of ponderosa pine – southern California and Sierra Nevada-Cascades – and possibly even a third—northern Coast Ranges. And there may be a difference between the trees found in the central Sierra Nevada and in the Cascades.

Trees in the southern California mountains typically lack 3-carene and have large amounts of β-pinene. However, 3-carene begins to appear more often in trees and in increasing amounts as a northward direction is pursued in the southern California mountains and into the southern end of the Sierra Nevada.

In the Sierra Nevada-Cascades, trees have much less β-pinene and much more 3-carene than those from the southern California mountains. It is not

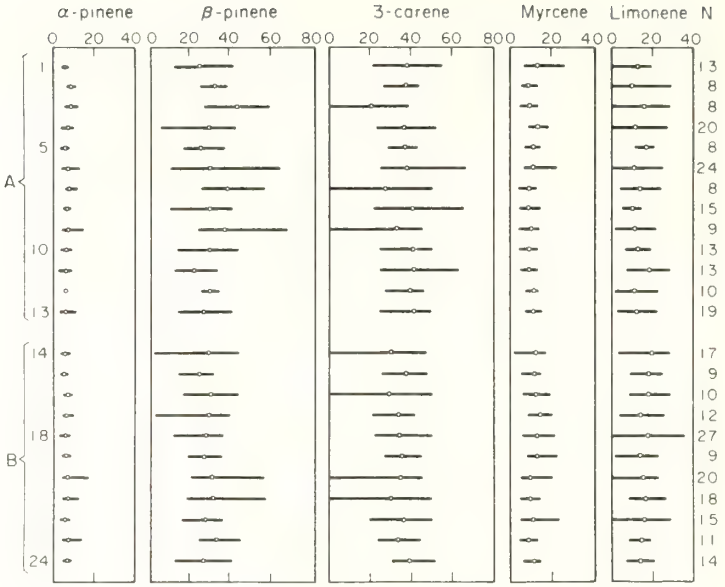

Figure 3.—*Mean (o) and range (–) in percent of the five major monoterpene components in plots 1 to 24 of ponderosa pine in El Dorado County, Calif.:* A, *at different elevations decreasing from 6,700 feet at No. 1 to 1,800 ft. at No. 13, with Nos. 8, 9, and 10 all at 2,700 ft.;* B, *at 3,500 ft. ± 300 ft. elevation. N is number of trees per plot.*

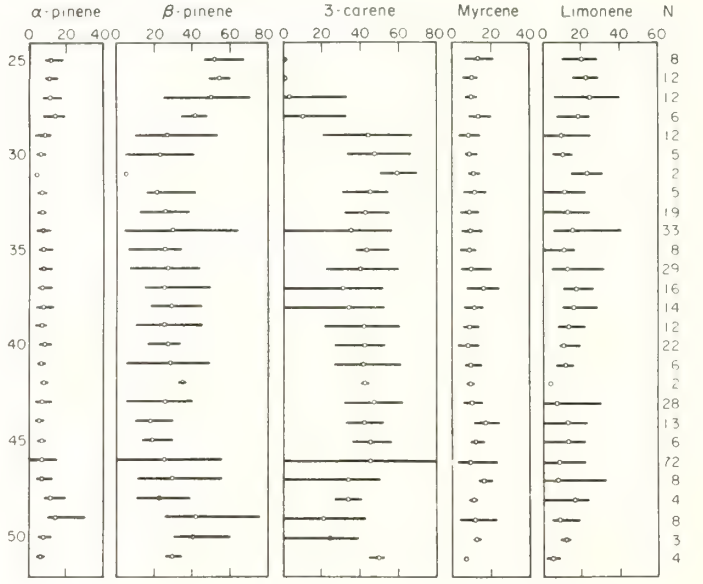

Figure 4.—*Mean (o) and range (–) in percent of the five major monoterpene components in plots Nos. 25 to 51 of ponderosa pine in counties of California. Plots Nos. 37, 44, and 46 are natural plots; the remainder are plantation plots. Plot numbers refer to figure 2. N is number of trees per plot.*

unusual to find trees with near-equal amounts of β-pinene, 3-carene, and a somewhat less amount of limonene.

Trees in the northern and central Coast Ranges appear to be somewhat intermediate between the southern California type and the Sierra Nevada-Cascades type in the percentages of 3-carene and β-pinene. The average α-pinene is above 10 percent in both the southern California mountains and northern Coast Ranges.

The Cascades and the Sierra Nevada differ in at least one component if a large sample of trees is used for an analysis. Limonene was found to be significantly greater in 78 trees from the three central Sierra Nevada plots than in 49 trees in three Cascade plots ($\bar{X}_1 - \bar{X}_2 = 7.9$ percent, t = 1.93, t.05 = 1.67).

The highest average for 3-carene, about 60 percent, was found in Fresno County (plot 31), but the plot consisted of only two trees and therefore may not be too representative. The average for 3-carene levels off to about 40 percent to the north. It again rises in the Cascades, going above an average of 45 percent. Individual trees with the highest 3-carene, nearly 80 percent, are found in the Warner Mountains

in the extreme northeast corner of the State; 3-carene may be absent from any of the three regions of the State.

The average for limonene is highest in the southern California mountains, but its range is not appreciably greater than in other regions of the State. Trees without limonene occur most often in the Cascades.

Two trees which might be classed as hybrids between ponderosa pine and Jeffrey pine *(P. jeffreyi* Grev. & Balf.*)* were found during this study in the plantations at IFG; none was found in natural plots. One of the hybrids was from Kern County, the other from El Dorado County. In both instances, the composition of these two trees was similar to the artificially produced F_1 (Smith 1967). Probably not more than 100 to 200 of the trees sampled came from the zone common to the range of the two species. Artificial hybrids between ponderosa and Jeffrey pine have been developed (Liddicoet and Righter 1960), and natural hybrids have been found (Haller 1962).

Western North America

Figure 5, arranged in the numerical order given in figure 1, is the average and range for each plot outside California.

At least two types of ponderosa pine, in addition to those in California, may be distinguished in western North America; and several intermediate ones may exist. A large amount of α-pinene generally characterizes trees from Arizona, particularly southern Arizona; the average for the other four major terpenes is quite low. However, some individual trees are not too different from those in other regions.

Northward from Arizona, trees tend to have a larger amount of 3-carene. Though the data show a clear break in the high α-pinene and high 3-carene between Arizona and the Wyoming and Nebraska plots, the sampling was insufficient to establish a cline or a clear break. There are irregular shifts from northern Wyoming through British Columbia to western Oregon, particularly in the mean and range of β-pinene and 3-carene. The amounts of myrcene and limonene may increase as the circuit is traversed. The Carter County, Mont., plot No. 62 is difficult to explain, since it resembles the southern Rocky Mountain plots as much as nearby plots.

There is a shift toward less 3-carene southward from Washington to southern Oregon. There is a divergence in southern Oregon, with the samples from the more easterly counties resembling those of the Sierra Nevada-Cascades of California and the more westerly ones resembling the samples from northern California Coast Ranges.

The mean composition was calculated for plots which could be closely grouped geographically. Plots were grouped as follows, using the plot numbers of figures 1 and 2 and designating these groups by Roman numerals: I = plots 25, 26, 27, 28; II = plots 35, 36, 37, 38; IIa = plots 48, 49. 50, 51; IIb = plots 70, 72; III = plots 57, 58, 59, 60, 61; IIIa = plots 64, 65, 66, 67; IIIb = plot 56; IV = plots 52, 53. This grouping used 290 of the trees; the remaining trees were, very largely, from the Sierra Nevada and were considered superfluous in this regional picture. A few other trees outside California were not used, such as plots 54 and 55, which consisted of so few trees and which would not be geographically grouped with other plots.

From these data eight regional types of ponderosa pine, based on xylem monoterpenes, can be envi-

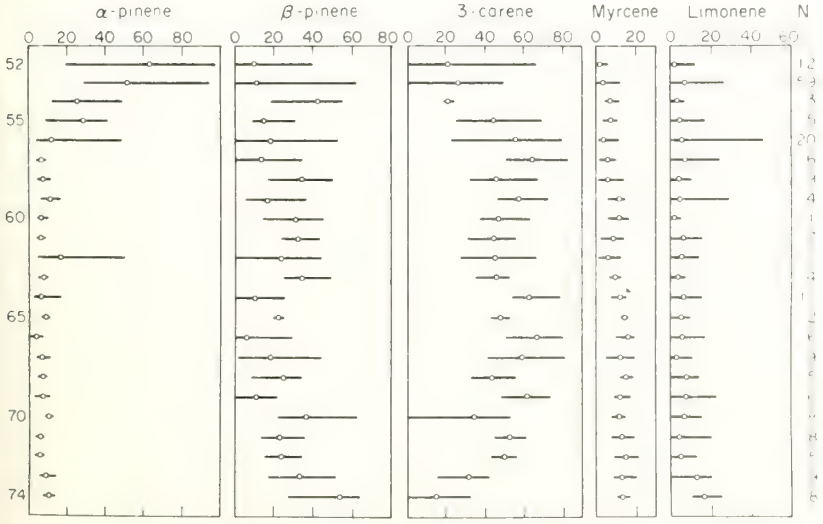

Figure 5.—*Mean (o) and range (–) in percent of the five major monoterpenes in plots Nos. 52 to 74 of ponderosa pine in western Canada and United States. All plots are plantations. N is number of trees per plot. See figure 1 for location of plot numbers.*

sioned *(fig. 6)*. A further breakdown of these was made into four major types–I, Southern California; II, Sierra-Cascade; III, northern-central Rocky Mountains; IV, Arizona–and four minor types–IIa, northern coast; IIb, central Cascade; IIIa, northern plateau; IIIb, central Rocky Mountains. Characteristics of the four major types are: I, high β-pinene; II, no component markedly higher than others; III, high 3-carene; IV, high α-pinene. Each of the four minor types is somewhat similar to a major type, yet has some distinctiveness. More thorough study now being made in the Arizona region may call for some changes in this classification.

A t-test was made between each of these eight regions for 3-carene by using arc-sin transformation of percents. The results *(table 1)* show a significant difference at the 99 percent level of confidence or greater in 23 of the 28 comparisons. Analyses of the other components are not presented because the statistical validity of comparing more than one element of a normalized system has been questioned.

These eight types do not fit the most recent subdivisions of ponderosa pine proposed by Wells (1964), who used seed and seedling characteristics to subdivide var. *ponderosa* into California and north plateau ecotypes, and var. *scopulorum* into southern, central, and northern ecotypes. For example, he establishes one type for California; we suggest three types.

General

The composition of individual trees varies widely throughout the range, and individual variants may be more meaningful than regional types. Twenty-five trees were selected to illustrate some of the individual variants of trees found in this study *(table 2)*. Bias was used in the selection to see how many types could be found in California. Most of the types listed

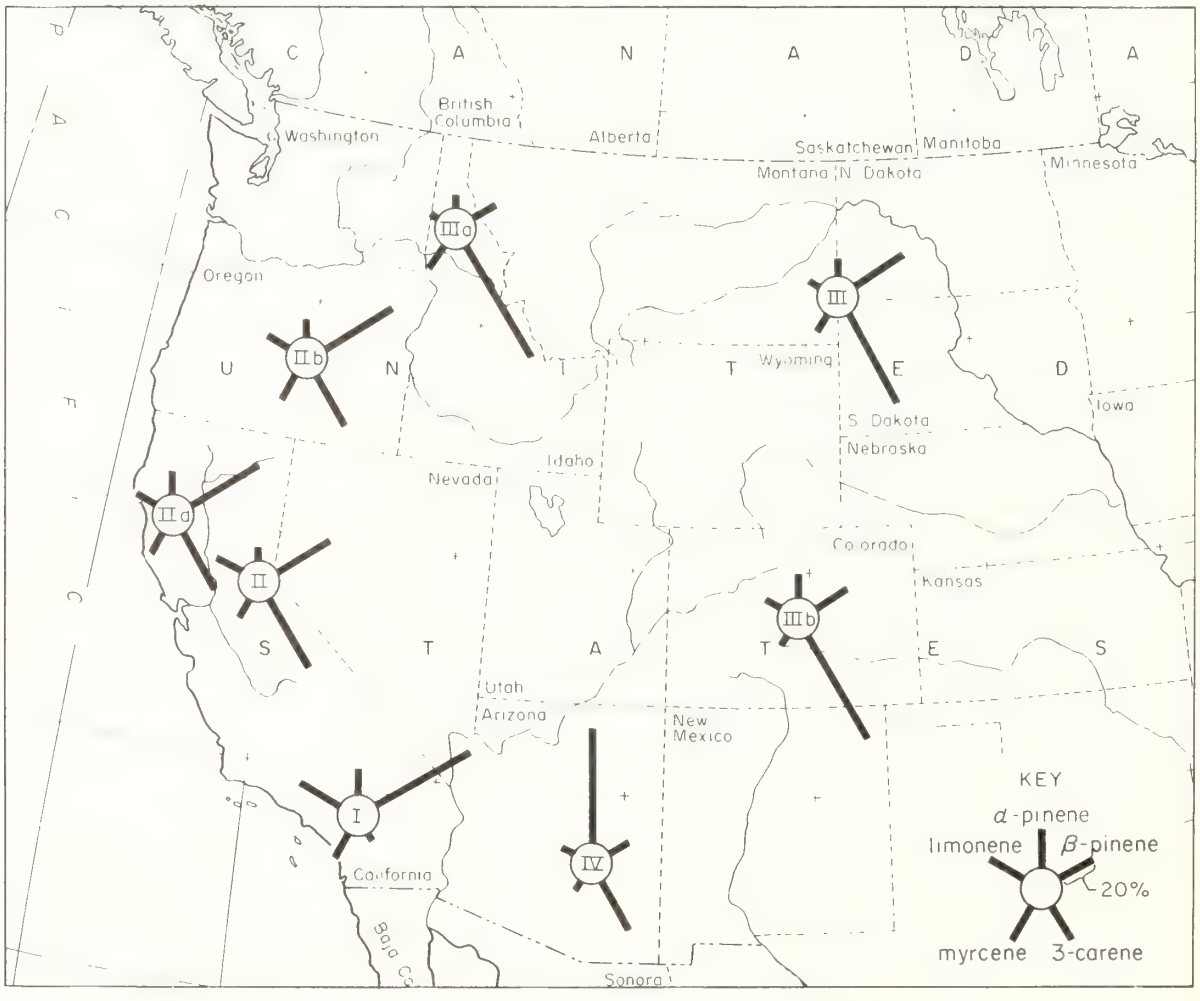

Figure 6.–*Mean monoterpene composition from plots of ponderosa pine in western North America.*

Table 1.– *Difference ($\bar{X}_1$ percent - $\bar{X}_2$ percent) in 3-carene for the eight regions shown in figure 6 and the 99 percent (**) confidence level of significance of this difference*

Region	No. of trees	II	IIa	IIb	III	IIIa	IIIb	IV
I	37	36.5**	27.4**	23.0**	47.9**	58.2**	53.5**	23.3**
II	55		9.1**	13.5**	11.4**	21.7**	17.0**	13.2**
IIa	18			4.4	20.5**	30.8**	26.1**	4.1
IIb	23				24.9**	35.2**	30.5**	.3
III	37					10.3**	5.6	24.6**
IIIa	28						4.7	34.9**
IIIb	20							30.2**
IV	72							

for California can be found outside the State. However, there was insufficient sampling to determine the diversity of types in each of the other regions. From this list it is evident that a large or small amount of one component may be associated with varying quantities of all the other four. The range of each major component was as follows: (a) α-pinene, 1 to 98 percent; (b) β-pinene, trace to 76 percent; (c) 3-carene, trace to 81 percent; (d) myrcene, trace to 25 percent; and (e) limonene, trace to 46 percent.

On the other hand it was possible to find a "typical" tree in every region except Arizona. Twenty-six trees were selected from all regions except southern Arizona to show this narrow range. Tree No. 21 in table 2 approximates this average tree. The

Table 2. – Monoterpene composition of individual ponderosa pines selected to show the wide range of types and association

Tree no.	Plot no.	α-pinene	α-thujene	Camphene	β-pinene	3-carene	Sabinene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Terpinolene
		Percent										
1	52	84.6	-	0.5	1.0	–	0.5	0.5	11.8	[1]	[1]	1.2
2	52	98.2	–	.7	.7	–	[1]	.4	[1]	[1]	–	–
3	52	28.6	–	.2	26.0	40.1	–	1.8	[1]	.4	[1]	2.9
4	52	70.7	[1]	.2	.6	[1]	11.2	5.4	.8	.4	[1]	10.7
5	56	47.1	–	.7	2.6	[1]	–	1.3	46.3	2.0		-
6	53	35.1		[1]	.3	31.8		3.4	26.4	[1]	[1]	3.0
7	69	9.0	[1]	[1]	.6	53.9	–	11.5	23.1	[1]	[1]	1.9
8	35	7.8	[1]	[1]	31.7	43.7	–	13.2	.4	.8	[1]	2.4
9	41	4.8	[1]	[1]	50.8	26.0	–	8.6	8.9	.3	[1]	.6
10	48	19.9	–	[1]	39.1	26.5	–	13.2	[1]	[1]	[1]	1.2
11	28	16.9	–	.3	48.0	[1]	–	8.8	24.6	1.4	–	–
12	31	3.2	[1]	[1]	5.6	48.3	–	8.7	31.5	[1]	[1]	2.5
13	49	30.5		.4	41.1	[1]	–	24.1	.7	3.2	-	
14	38	5.9		[1]	29.4	26.8	–	10.5	24.8	1.3	[1]	1.3
15	26	8.5	–	[1]	52.4	[1]	–	10.0	28.6	.5	–	
16	36	7.7	[1]	[1]	8.9	65.9	–	8.5	5.0	.9	[1]	3.1
17	34	10.2		[1]	36.4	[1]	–	11.4	42.0	[1]		-
18	34	3.3	[1]	[1]	3.3	57.4	-	16.4	16.9	[1]	[1]	2.7
19	46	7.9	[1]	[1]	22.1	59.3	–	6.4	.3	.8	.1	3.0
20	46	1.0	[1]	.3	.3	80.6	–	12.3	[1]	1.0	.6	3.9
21	46	5.5	[1]	[1]	27.6	38.1	–	13.5	13.5	[1]	[1]	1.8
22	49	19.5	-	[1]	75.8	[1]	-	2.9	.6	1.2		
23	44	4.9	[1]	[1]	25.8	40.8	–	23.6	.8	1.2	.3	2.4
24	44	4.3	[1]	[1]	9.2	39.7	–	24.8	19.1	1.7	[1]	1.2
25	36	4.0	[1]	[1]	14.4	27.3	–	24.9	26.5	1.8	[1]	1.1

[1] Trace amount.

range of the five major components in these selected trees was as follows: (a) α-pinene, 5 to 11 percent; (b) β-pinene, 20 to 55 percent; (c) 3-carene, 19 to 55 percent; (d) myrcene, 3 to 15 percent; and (e) limonene, trace to 17 percent. Thus, though there are numerous types of individual composition extremes which might lead one to fragment the pine into a number of variants, there is also a thread of "standard" trees which binds the species together.

The coefficient of variation, calculated from arcsin values, of each component in each plot *(fig. 7)* shows limonene to be by far the most variable component, having the highest coefficient of variation in 48 out of 74 plots. Increasing the sample size did not, in general, decrease this coefficient. This relationship was particularly evident in the two Modoc plots, Nos. 45 and 46.

Several ponderosa pines also were found to have a monoterpene composition like Washoe pine *(P. washoensis* Mason & Stockwell*)*. In this study, trees Nos. 16 and 20 in table 2 approximate the monoterpene composition of this pine. This composition is somewhat characteristic of trees from the north-central Rockies. Haller (1962) suggests that Washoe is related to ponderosa. Mirov (1961) suggested that it is a chemical mutant of ponderosa or a hybrid between two varieties of ponderosa, one of which may now be extinct. On the basis of monoterpene studies, this relationship would appear to be closest to trees in the north central Rockies.

Three-carene may provide a clue to the type of inheritance in a tree. This component is found either in trace amounts or in an amount in excess of about 20 percent; there is no percentage between. The maximum amount found was nearly 80 percent. But between 20 and 80 percent there is no distinct 20 percent grouping.

Variations in Minor Components

The analysis of minor components provided little help in understanding the species. It was difficult to work with the minor components because they often eluted during chromatographing near a major com-

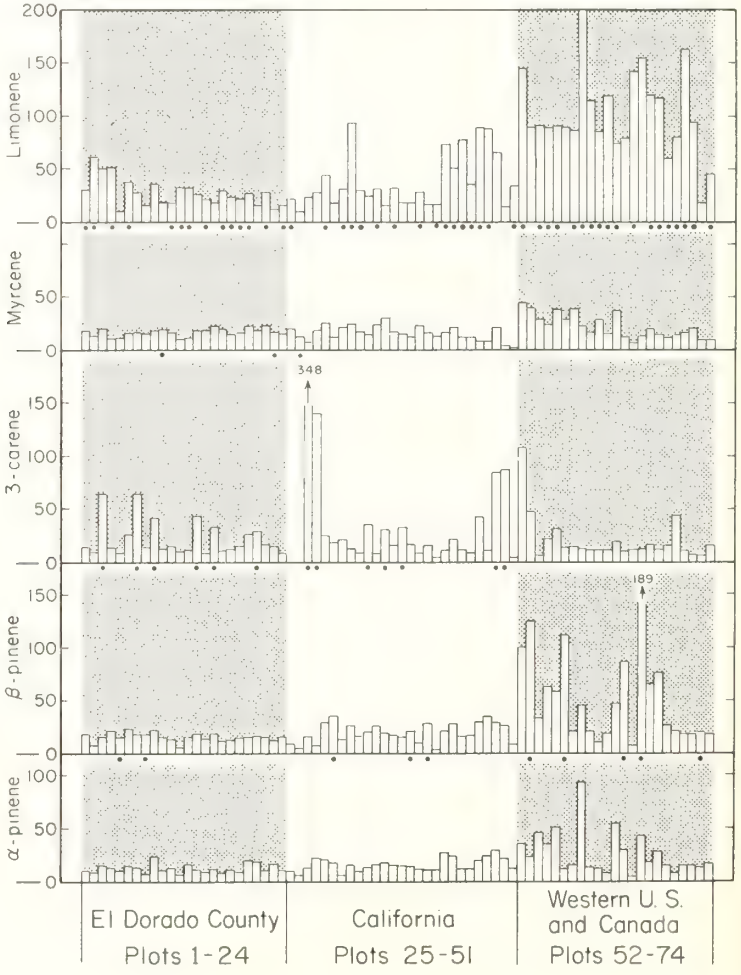

Figure 7.—*Coefficient of variation for the five major monoterpene components of ponderosa pine xylem resin from 74 sources. Plot numbers run consecutively from left and refer to figures 3, 4, and 5; • denotes component from each source with the largest coefficient.*

ponent. And a large amount of the major component may mask the presence of the trace amount of the minor component. This difficulty was most apparent in working with sabinene and 3-carene.

One or more of seven minor components—heptane, α-thujene, camphene, γ-terpinene, sabinene, β-phellandrene, and terpinolene—were found in trees in all regions. Traces of heptane were found in trees from Utah, Colorado, and California. One tree from Utah may have a trace of nonane. Traces of α-thujene, camphene, and γ-terpinene were found in some trees in all regions. Camphene tended to be in measurable amounts, between 0.1 and 0.5 percent, in trees from the southern Rockies. Sabinene was found in small amounts in trees from Cochise County, Ariz., plot 52; one particular tree had 11 percent. Sabinene was not found in all trees from Arizona. It may occur in trees in other regions, but the chromatographic procedures will have to be improved to detect it with more assurance. Undecane was found in trees in four counties in California—Santa Cruz, Kern, El Dorado, and Lassen—and in Utah. Mirov (1961) found undecane in trees from Santa Cruz County, Calif., and considered this a link between ponderosa and Coulter, *Pinus coulteri* D. Don. This might now be questioned, since no undecane was found in the southern California mountains where ponderosa and Coulter often grow together.

Two minor components, β-phellandrene and terpinolene, occur in measurable amounts in all regions; β-phellandrene averages about 1 percent, with a high near 3 percent; terpinolene averages about 2 percent, with a high near 10 percent. This 10 percent was uniquely associated with the 11 percent sabinene; without this particular tree the high would be about 6 percent. Outside southern Arizona the presence of γ-terpinene and terpinolene is associated with 3-carene; trees without 3-carene have neither of these two; when 3-carene is high these two are comparatively high.

DISCUSSION

Any explanation of the lack of coincidence of the range of ponderosa pine and the western pine beetle is still quite speculative. The distribution of the beetle (Miller and Keen 1960) generally follows the distribution usually assigned to var. *ponderosa.* The average monoterpene composition of trees in this distribution tends to have a more even concentration of the five major monoterpenes than that of trees in other regions, though individual trees exhibit a wide variation. The beetle is not found in the region assigned to var. *scopulorum,* where trees tend to have a high concentration of 3-carene. Likewise, the beetle is not found in regions assigned to var. *arizonica,* where trees tend to have a high concentration of α-pinene. The southwestern pine beetle, which has habits quite similar to those of the western pine beetle, however, is found in this region. Therefore, the western pine beetle tends to be associated with ponderosa pine where no monoterpene occurs as a large percentage of the composition in the average tree, with one exception; in southern California, the beetle occurs where the average pine has a large percentage of β-pinene.

The study did little to clarify the taxonomy within ponderosa pine; in fact, it may have added to the uncertainty which now exists. Trees in southern California have always been grouped with var. *ponderosa,* yet the trees in that region are as chemically distinct as trees assigned to regions of var. *scopulorum* and var. *arizonica.* Likewise, trees in Arizona are often split between var. *scopulorum* in the north and var. *arizonica* in the south; yet, chemically, they may be quite similar. Appreciable differences in average values can be found from region to region. However, the range of values for the various monoterpene components often overlaps. In most cases the sampling in this study probably was too restricted to demonstrate the existing variation. Larger and more extensive samples would be needed before real differences can be confidently ascertained.

Our data, covering the Western United States, and Mirov's (1961) show similarities as well as differences. Mirov did not report large local variation, particularly of trees either nearly lacking or having large amounts of 3-carene, β-pinene, α-pinene, and limonene. He also reported generally smaller amounts of myrcene, limonene, β-phellandrene, and terpinolene. And he did not report small amounts of heptane, α-thujene, sabinene, and γ-terpinene.

Several studies, in addition to the more extensive and intensive sampling, are suggested by these results. The use of more sensitive chromatographic detectors would enable more work to be done on the minor constituents. Possibly these minor constituents may help clarify taxonomical relationships as well as or better than the five major constituents. The chemical

relationship between ponderosa and Washoe pine needs additional work. An investigation of the sesquiterpenes and diterpenes could reveal valuable data about resin properties.

SUMMARY

A gas chromatographic analysis of the monoterpenes of 927 ponderosa pines, representing to some degree a major portion of the species' range, showed considerable local and regional diversity in composition. Five major monoterpenes– α-pinene, β-pinene, 3-carene, myrcene, and limonene–were analyzed. There is some evidence to support the establishment of at least eight regional types of ponderosa pine, and a further breakdown of these into four major and four minor ones on the basis of greater differences. More meaningful than regional types may be individual tree variants; at least 25 of these have been identified. However, despite regional types and the large number of individual variants, trees with similar composition were found in all regions except southern Arizona. Limonene had the largest coefficient of variation in 48 of 74 plots. Neither elevation nor age of the tree had an apparent effect on composition. Minor components found were heptane, α-thujene, camphene, sabinene, undecane, β-phellandrene, γ-terpinene, and terpinolene; however, only the last three were commonly found.

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REDUCING FIRE HAZARD IN PONDEROSA PINE THINNING SLASH BY MECHANICAL CRUSHING

John D. Dell Franklin R. Ward

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The Authors

are studying problems of reducing fuel hazard in the Douglas-fir region by prescribed burning and other methods. They are headquartered in Portland, Ore. **JOHN D. DELL** attended Humboldt State College, and joined the Forest Service in 1956. **FRANKLIN R. WARD** became a member of the Station's fire research staff in 1966, after earning an M.F. degree at Utah State University.

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We thank Don Peters and Don Franks, fire control staff, Deschutes National Forest, for their help in finding test plots and arranging for the necessary equipment. The cover photo was provided by Don Peters. We appreciate the assistance of personnel from the Fort Rock Ranger District in preparation of test plots and in collecting some of the data. We thank Charles Mathers of the Young Corporation, Seattle, Washington, for arranging the loan of the "Tomahawk" for this study, and the Colville National Forest, Colville, Washington, for the loan of its Marden brushcutter.

Precommercial thinning of ponderosa pine *(Pinus ponderosa* Laws.*)* stands is a widespread practice in the Western United States and more acreage is being thinned than ever before. In the pine stands of the Pacific Northwest, thinning can increase diameter growth of crop trees by 30 to 150 percent. And it usually accelerates height growth.[1] Thinning will usually eliminate trees in poor form or of undesired species. Costs of thinning may well be repaid by shortening the time required to grow merchantable trees.

But the slash from thinning, if allowed to accumulate, can be a serious fire problem. In areas of low rainfall and low humidity, it can be a high to extreme fire hazard for 5 years or longer.[2,3] If the benefits of precommercial thinning are to be realized, stands must be protected from fire. An effective, economical method of treating slash is needed. One method of treating slash may be to crush and compact it.

This paper reports a study of mechanical crushing on the Deschutes National Forest in central Oregon. Three types of mechanical crushers were compared for their effectiveness in reducing fire hazard in ponderosa pine thinning slash. Data on costs and time required in both green and red slash by each method were collected.

In this study, the specific aims of slash treatment were (a) to interrupt the fuel continuity and scarify the ground to reduce rate of fire spread and resistance to control,[4] (b) to break up slash into smaller fuel components to hasten decomposition, (c) to compact the fuel so as to increase chances for decay, (d) to provide greater access to stands, (e) to make the forest more esthetically pleasing, and (f) to accomplish these aims without excessive damage to the residual stand.

EQUIPMENT TESTED

For this study, we had to use equipment that was expected to accomplish our objectives in fuel treatment and, at the same time, to maneuver between residual trees without causing excessive damage. We tested the following equipment:[5]

Caterpillar Tractors, D-7 and D-6

A D-7 crawler tractor was used for crushing the green slash. A D-6 was used on the 1-year-old red slash. Neither tractor had any special attachments. The weight of the tractors and the action of their grousers were used to crush and compact the fuel. Both tractors were rented locally, with operators.

"Tomahawk" Compactor-Cutter-Crusher

The "Tomahawk"[6] is a dual-purpose machine *(fig. 1).* It is designed for crushing and compacting in roadwork or, with alternate compaction and brush-cutter rings, for brush-clearing operations. It has been used for preparing fuel-breaks in southern California with good results. But the "Tomahawk" had never been tested on logging or thinning slash.

In this study, the "Tomahawk" was attached to the blade of a D-6 tractor. The model used was 6-feet wide and weighed 2,740 pounds. Other widths are manufactured, but the 6-foot model was selected because of its availability.

---

[1] Mowat, Edwin L. *Thinning ponderosa pine in the Pacific Northwest.* U.S.D.A. Forest Serv. Res. Paper PNW-5, Pacific NW. Forest & Range Exp. Sta., Portland, Ore. 24 p. 1953.

[2] Fahnestock, George R. *Fire hazard from precommercial thinning of ponderosa pine.* U.S.D.A. Forest Serv. Res. Paper PNW-57, Pacific NW. Forest & Range Exp. Sta., Portland, Ore. 16 p., illus. 1968.

[3] Wilson, Kenneth O. *Piling and burning slash in Oregon eastside pine.* (Paper presented at fall meeting, California-Nevada Forest Fire Council, Lake Tahoe, Calif., October 24-25, 1967.)

[4] As defined in *Glossary of terms used in fire control.* U.S. Dep. Agr. Handb. 104, U.S. Govt. Printing Office, Washington, D. C. 1956.

[5] Trade names and commercial enterprises and products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

[6] Manufactured by the Young Corporation, 2917 E. Marginal Way S., Seattle, Washington.

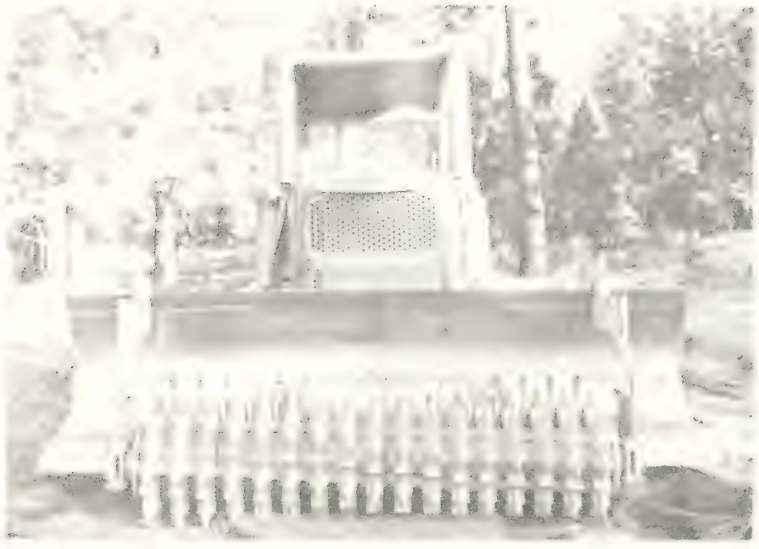

Figure 1.–*The "Tomahawk" crusher has 17 alloy steel rings keyed in a spiral. Rings are 24 inches in diameter, with eight half-round cutter segments protruding 2-1/2 inches above 16 crusher segments. Weight per ring is 89 pounds.*

Figure 2.–*The Marden brushcutter has been used extensively for land clearing in southeastern United States and, more recently, in lodgepole pine logging slash in the West.*

Marden Brushcutter

The Marden brushcutter[7] is a hollow steel cylinder, with cutting blades on the rolling surface *(fig. 2)*. Brushcutters and similar equipment are designed for a variety of land clearing and cultivating uses. Larger tractors are required for hauling this equipment.

The Model SB-8 used in this study was towed behind the D-7 tractor. It is 8 feet wide, has a drum diameter of 5 feet, and a water (or diesel) holding capacity of 1,100 gallons. It weighs more than 16,000 pounds when empty, about 25,000 pounds filled.

PROCEDURE

The study was conducted in spring of 1968 in thinning slash on a 40-year-old ponderosa pine stand. Eight 5-acre study plots were set up in fairly homogeneous slash on generally level ground. Fuel treatment by mechanical crushing was applied under two different fuel conditions: (a) three plots of

[7] Manufactured by the Marden Manufacturing Company, 205 Denton Avenue, Auburndale, Florida. Equipment similar to the Marden brushcutter is manufactured by several other companies, including: Fleco Corporation, Jacksonville, Florida; Tom Billings Company, Orlando, Florida; and Rockland Company, Winter Garden, Florida.

current (green) thinning slash, and (b) three plots of 1-year-old (red) thinning slash. The other two plots–one in each fuel condition–were not treated, and served as controls. The green slash areas were thinned to 20- by 20-foot spacing, with about 110 leave trees per thinned acre. The red slash area was originally thinned to 16- by 16-foot spacing, with about 170 leave trees per acre. Before thinning, general stand density ranged from 3,000 to 5,000 trees per acre. Using Fahnestock's[8] thinning slash weight tables, we determined fuel weights to be between 35 and 45 tons per acre.

In addition to these eight plots, we also set up three 1-acre test areas in rocky, rough, and sloping slash areas where effectiveness of each piece of equipment under adverse operating conditions was evaluated.

The mechanical crushing equipment used in the study was required to make two passes over each plot–one perpendicular to the other. The time required for each treatment and costs were recorded.

Fuel Hazard Rating

Rate of fire spread and resistance to control conditions were determined for each plot, both before and after treatment, by four local fire control specialists. The fuel type identification system of the Forest Service's Pacific Northwest Region[9] was used to determine the degree of fire hazard and its reduction as result of treatment. In this system, fuels are classified by one of four rate-of-spread and one of four resistance-to-control categories, making 16 possible fuel-type combinations. The four categories in both classifications are: (a) Extreme (E), (b) High (H), (c) Moderate (M), and (d) Low (L). Thus, a fuel type designated by the symbol EH, means *Extreme High* for an *Extreme* rate of spread and *High* resistance to control. Fuel hazard ratings were based on what the evaluators could observe from a fixed point located in the center of each plot.

Plot Sampling

Sampling to determine number and vertical distribution of woody stems was done before and after treatment on 22 square-yard, vertical-plane sub-plots located along a line transect in each 5-acre plot. A measuring device *(fig. 3)* was designed for this purpose. We recorded the number of stem intercepts by the vertical plane in which they occurred. Fuels were classified by these diameters: (a) up to .50 inch, (b) .50 inch to 4 inches, and (c) 4 inches and more.

Exposed soil intercepted on each plot was recorded before and after treatment to determine effects of scarification. The amount exposed was estimated as a percentage of the 3-foot line that fell below the lowest cross-stick on the plot measuring device.

Damage Appraisal

On 1-acre sub-plots in each treatment, we recorded the number of residual trees damaged or killed by one or more of these categories: (a) bark skinned off bole, (b) broken limbs, (c) tree knocked askew but still alive, (d) visible root damage, and (e) tree definitely killed (uprooted, etc.).

Equipment Evaluation

Equipment performance and maneuverability in the thinned stand was evaluated subjectively for each treatment.

Figure 3.–*A plot measuring device was used, before and after treatment, to measure fuel amount and distribution at 1-foot intervals on a vertical plane. A die was cast at each plot measuring point to determine orientation of the plane in relation to the transect line.*

[8] See footnote 2.

[9] U.S. Forest Service Pacific Northwest Region. *Guide for fuel type identification –Region 6.* Portland, Ore. 48 p., illus. 1968.

RESULTS

Reduction of Fire Hazard

Fuel hazard ratings were made three times in each plot: (a) before treatment, (b) after one pass of the equipment, and (c) after two passes. In all instances, except one, a single pass reduced at least one component of the hazard rating. In three of the six instances, the second pass reduced the rating further. A rating of MM was achieved on three of the six test plots. This rating is considered an acceptable hazard level for ponderosa pine thinning slash areas in the Pacific Northwest Region.[10]

The most obvious effect of all three methods of treatment in both green and red slash was the change in vertical distribution of the fuels. We found that crushing had compacted to within 1 foot of the ground more than 90 percent of fuels tallied above the 1-foot level before treatment *(table 1)*. Cutting and chopping the slash into smaller components was difficult for the D-6 or D-7 alone. With the "Tomahawk" attached to the D-6, however, slash breakdown was considerably improved.

Fuel treatment with the "Tomahawk" crusher most nearly met the six objectives of the study. The attachment proved effective in treating green thinning slash. It lowered the hazard rating in this fuel from HH to MM *(table 2)*. In heavier loadings of red slash, it changed the rating from HE to MM *(fig. 4)*. The "Tomahawk" treatment was the most effective for mulching finer fuels with soil and for redistributing fuels over a larger ground area. It could cut and chop fuels up to 4 inches in diameter. The larger fuels, 6 to 8 inches in diameter, were scarred, de-limbed, and compacted close to the ground.

The D-7 tractor did not prove satisfactory in crushing green slash because it could not break up and mulch small fuels. This treatment made some changes in the fuel *(fig. 5)*, but not enough to reduce the original rating (HM). In red slash, however, two passes with the smaller D-6 tractor reduced a heavy fuel concentration from EE to HM. The more complete breakdown of the red slash was attributed to its dry, brittle condition. The tractors by themselves did not prove as effective for chopping the fuels into smaller components as they did when the "Tomahawk" and Marden units were attached.

The Marden brushcutter was effective for crushing and breaking up thinning slash where it could operate, but its size caused handling difficulties in close quarters. It could chop through fuels in the 6- to 8-inch category– cutting them into 1- and 2-foot lengths. Fuel type classification in green slash after this treatment dropped from EE to HM. In red slash, the rating was changed from HM to MM *(fig. 6)*.

Table 1.–*Percent of fuels compacted to within 1 foot of the ground*

Equipment tested	Green slash	Red slash
Tractor	[1]99	[2]93
D-7 tractor with Marden brushcutter	98	89
D-6 tractor with "Tomahawk"	97	97

[1]D-7 tractor.

[2]D-6 tractor.

Table 2.–*Fuel hazard ratings*[1] *for 5-acre study plots, before and after mechanical crushing*

Equipment used and slash condition[2]	Before treatment	After one pass	After two passes
Tractor:			
green slash	HM	HM	HM
red slash	EE	HH	HM
D-7 tractor with Marden brushcutter:			
green slash	EE	HH	HM
red slash	HM	MM	MM
D-6 tractor with "Tomahawk":			
green slash	HH	HM	MM
red slash	HE	MM	MM

[1]H = high, M = medium, and E = extreme.

[2]D-7 tractor used in green slash, D-6 tractor in red slash.

Ground Scarification

Both the "Tomahawk" and the Marden brushcutter did a more effective job of ground scarification than the tractors *(table 3)*. The tractors failed to penetrate the soil deep enough with their tracks and, therefore, could not produce the "mulching" effect of the "Tomahawk" or Marden.

[10]Wilson, K. O. Memo to Forest Supervisors, Division Chiefs, and Rangers, R-6, 5150 Prescribed Burning (slash treatment policy), October 23, 1968.

Figure 4.–*Treatment of slash by the "Tomahawk" crusher reduced the fire hazard rating from HE (high, extreme),* top, *to MM (moderate),* bottom.

Damage to Residual Trees

The Marden brushcutter injured more of the leave trees than either the two tractors or the D-6 tractor with "Tomahawk" attached. It did most of the damage by scarring tree boles. Only five trees on the 1-acre sub-plot were knocked askew. Considerably fewer trees were damaged in the 20- by 20-foot spacing than in the 16- by 16-foot spacing *(table 4).*

Equipment Performance

The "Tomahawk" attachment in no way impaired the maneuverability of the D-6 tractor in the close spacing of the thinned stand. The assembly was simple to transport and handle–requiring only 5 minutes to attach or detach from the tractor blade. This attachment also proved quite durable on rocky ground, and showed almost no wear after the study was completed. On the rough 1-acre testing ground, the D-6 with "Tomahawk" functioned efficiently both up and down slope. Contouring on steep slopes,

Table 3.–*Percent of mineral soil exposed on measured sub-plots*

Equipment used and fuel condition[1]	Before treatment	After treatment
Tractor:		
green slash	10	25
red slash	18	6
D-7 tractor with Marden brushcutter:		
green slash	25	31
red slash	9	32
D-6 tractor with "Tomahawk":		
green slash	14	50
red slash	4	26

[1]D-7 tractor used on green slash, D-6 tractor in red slash.

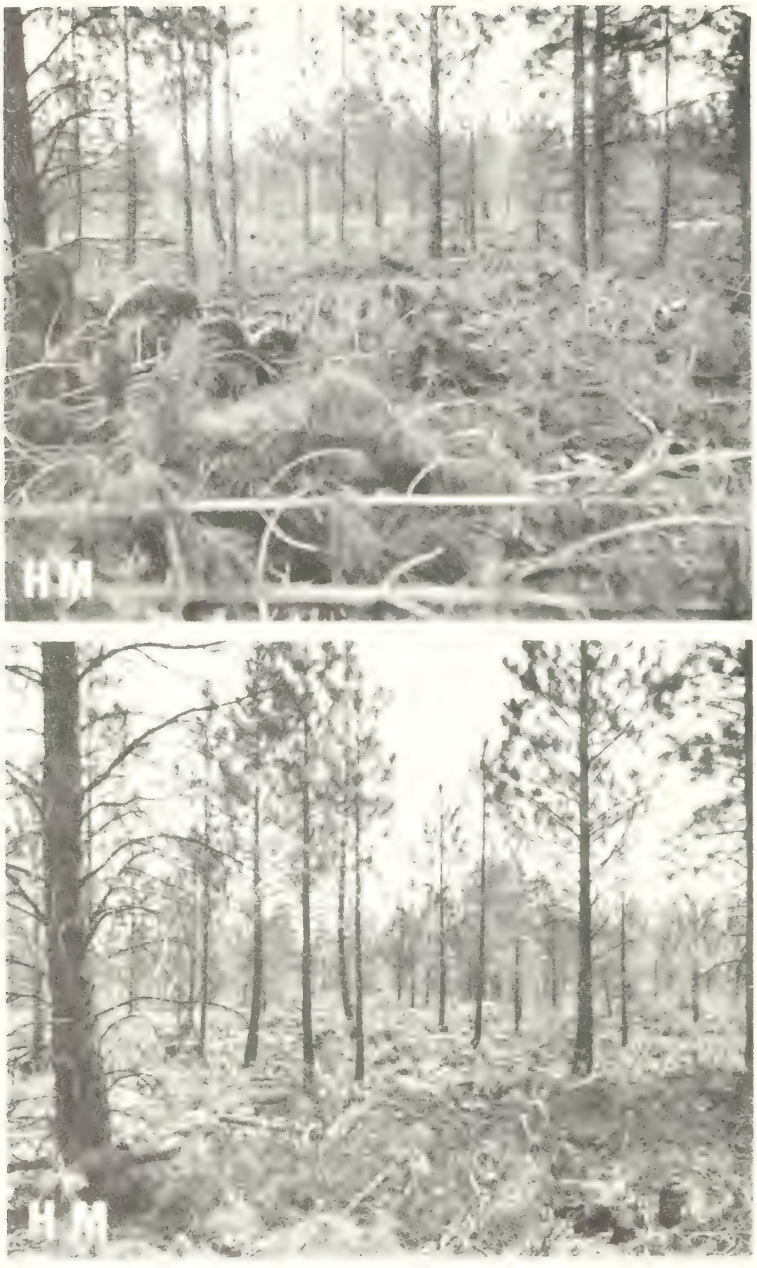

Figure 5.–*Tractor crushing in fresh, green slash modified the vertical distribution of the fuels somewhat, but not enough to change the original hazard rating.* Top, *before treatment;* bottom, *after two passes by the tractor.*

however, was not effective with any of the equipment.

In the plots in which tractors alone were used, the D-7 showed no advantages in fuel treatment over the smaller D-6. The smaller tractor has a size advantage, and handles well in the thinned stand. Caterpillar tractors were used in this study, but similar size equipment, such as Allis Chalmer's HD 11, International Harvester's TD-15, or Euclid's 103-B, would probably perform equally well.

The Marden brushcutter did a good job of fuel treatment, but because of its size and poor maneuverability in the thinned stand, we do not recommend it for this work. It handled favorably on slopes to 35 percent, but its cutting knives were nicked and broken by the numerous rocks on the test area. A complete reconditioning, costing more than $200, was necessary after the study was completed. Movement of the Marden brushcutter from job to job is expensive, and requires special handling equipment.

The small stumps from thinned trees *(fig. 3)* did not prove to be obstacles to any of the equipment we tested. However, some caution was required to avoid larger stumps where recent commercial logging had preceded thinning–and where thinning slash obscured the stumps.

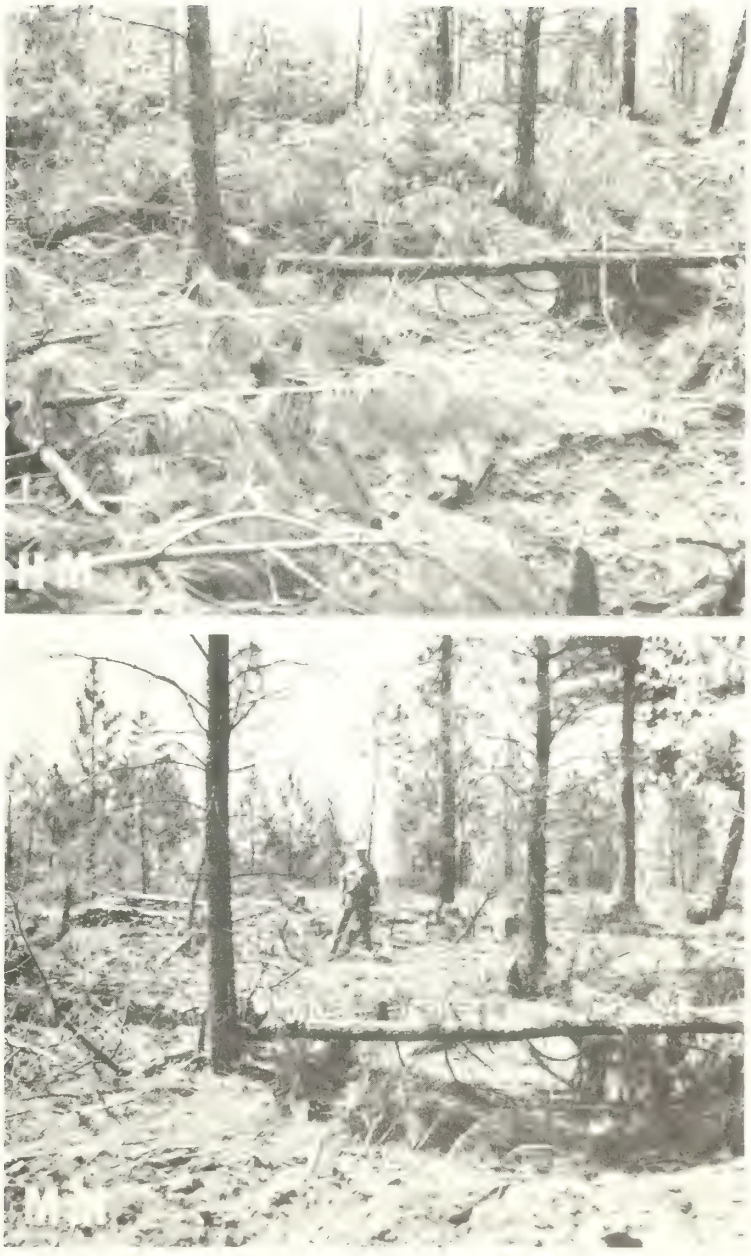

Figure 6.–*The Marden brushcutter was effective where it could reach, but had difficulty treating slash close to leave trees, as shown in the bottom photo.*

Time and Cost Factors

Cost figures from this study *(table 5)* reflect the rental rates we paid for the prime movers only. No effort was made to pro-rate costs for the "Tomahawk" or Marden assemblies that we obtained on loan. Nor are hauling or reconditioning costs for the Marden brushcutter included.

The "Tomahawk" in the study cost $3,270 retail. The manufacturer claims that only minor maintenance is necessary to keep the equipment operational, and that it has an estimated life span of 10 years with frequent rough use. The other attachment tested, the Marden brushcutter, cost about $8,000.

Fuel treatment with the "Tomahawk" required only slightly more time per acre than the other equipment. Condition of the slash (green or red) made little difference in time required for treatment with any of the equipment. On the rough-ground test areas, however, more time was needed by each piece of equipment in order to negotiate steep slopes and avoid rocky outcroppings.

Table 4.–*Number of leave trees damaged on 1-acre sub-plots, by type of damage and equipment used*

Equipment	Skinned bole	Broken limbs	Tree knocked askew	Visible root damage	Tree killed	Total	Percent leave trees damaged
20- BY 20-FOOT SPACING (110 LEAVE TREES PER ACRE)							
Tractor[1]	7	0	1	0	0	8	7.3
D-7 tractor with Marden brushcutter	19	0	1	0	0	20	18.2
D-6 tractor with "Tomahawk"	2	0	0	0	0	2	1.8
16- BY 16-FOOT SPACING (170 LEAVE TREES PER ACRE)							
Tractor[2]	20	0	1	0	0	21	12.4
D-7 tractor with Marden brushcutter	26	0	1	0	0	27	15.9
D-6 tractor with "Tomahawk"	11	0	1	0	0	12	7.1

[1]D-7

[2]D-6

Table 5.–*Time required for treatment and costs, by type of equipment tested and condition of slash*

Equipment	Condition of slash	Time required		Cost	
		Per acre	5-acre total	Per acre	5-acre total
		Hrs./min.		*Dollars*	
D-7 tractor[1]	Green	0:50	4:10	12.42	62.08
D-6 tractor[2]	Red	0:52	4:20	15.16	75.83
	Red[3]	1:15	--	21.87	--
D-7 tractor with Marden brushcutter[1]	Green	1:05	5:25	16.14	80.70
	Red	0:45	3:45	11.17	55.87
	Red[3]	1:15	--	18.62	--
D-6 tractor with "Tomahawk"[2]	Green	1:05	5:25	18.96	94.79
	Red	1:10	5:50	20.42	102.08
	Red[3]	1:40	--	29.16	--

[1]Rental charges: $14.90 per hour, including operators' wages, maintenance and operation.

[2]Rental charges: $17.50 per hour, including operators' wages, maintenance and operation.

[3]1-acre test plots located on uneven ground with slopes to 35 percent.

DISCUSSION AND CONCLUSIONS

Even a single pass of a crusher over slash can reduce its fire hazard, and may suffice to meet minimum fire control standards. Any additional passes further contribute to improved access and better appearance of the treated area. Intensity of treatment will depend on management objectives.

In extensive areas of continuous thinning slash, where total fuel treatment may not be feasible, a modified "fuel-break" system might be considered. Mechanically crushed strips or lanes could be located through the fuel complex to break up slash continuity, restrict free movement and spread of wildfire, and allow a line of defense for fire control work.

A "Tomahawk" crusher mounted on the blade of a D-6 tractor was the most useful tool tested for reducing fire spread potential and resistance to control of both green and dry thinning slash. It readily crushed and broke up small diameter slash and left it compacted close to the ground without interfering with maneuverability of the tractor, or causing damage to "leave" trees. We had no repair or maintenance problems.

The Marden brushcutter did a good job of fuel treatment on flat ground, but its cutting blades were damaged in rocky areas. Because of its large size and poor maneuverability in the thinned stand, this unit caused excess damage to leave trees and left considerable uncrushed slash close to them. The equipment is also expensive to move from job to job.

Tractors, by themselves, were satisfactory for crushing the brittle red slash, but were not effective in green slash. Neither were they as effective as the other equipment in mulching small fuels.

The "Tomahawk" attachment is available in several sizes. A 10-foot-wide assembly is recommended for future testing. This size will allow a wider swath to be treated on each pass, without hindering tractor maneuverability in the thinned stand. A dual tandem "Tomahawk" unit, or a larger diameter arbor assembly, might also increase effectiveness and should be tested.

The crawler tractor plays an important role in compacting the slash—whether used alone or with the "Tomahawk" unit attached. It would be advantageous, therefore, to test various tractors with different treads and grousers to determine which types are most effective for cutting and crushing thinning slash.

Future research on the study plots is aimed at determining (a) the effect of treatment on slash decomposition (compared with controls), (b) changes in fire hazard conditions on treated and untreated areas over a period of several years, and (c) ecological effects of treatment over a period of time.

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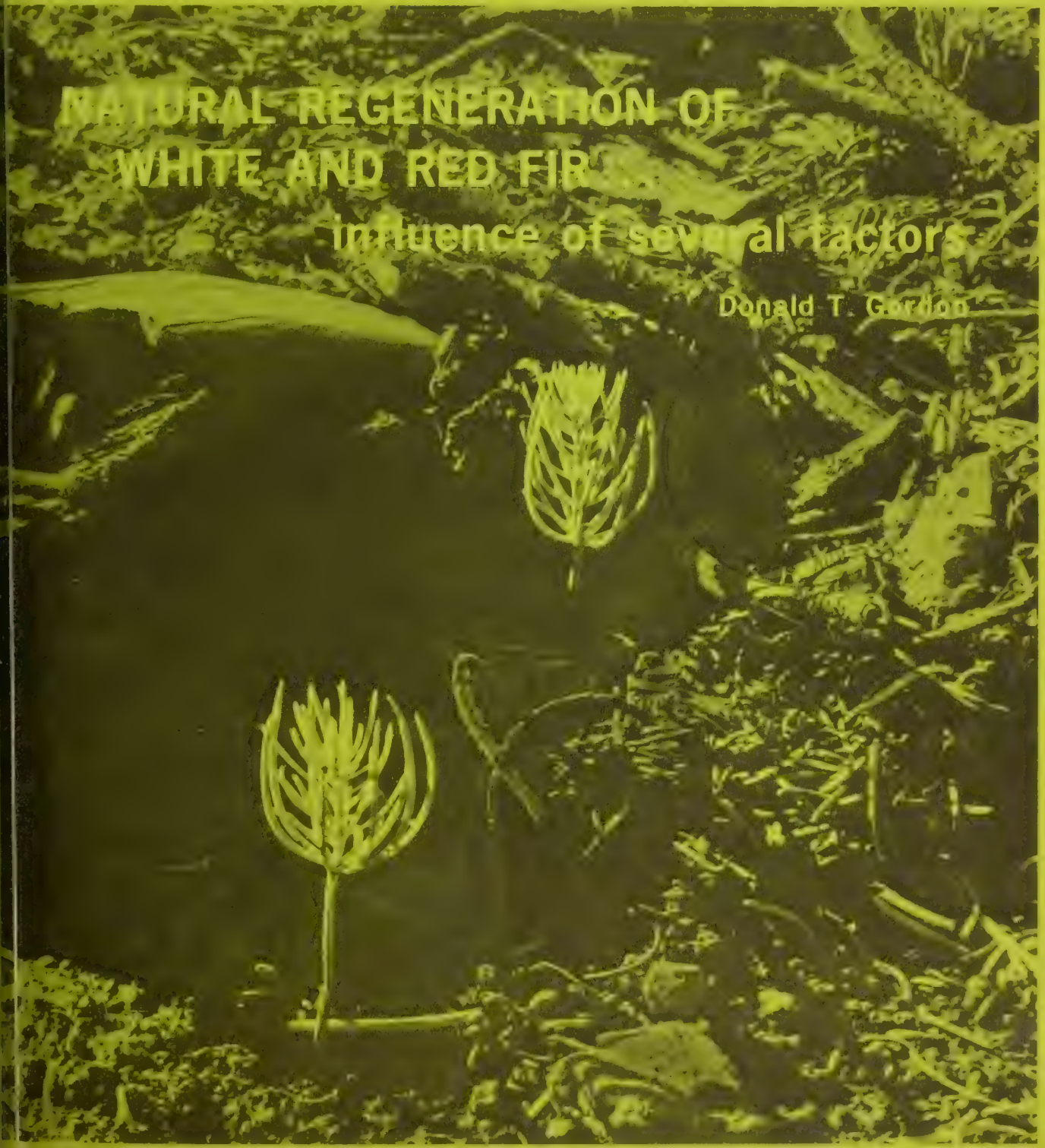

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The Author

DONALD T. GORDON is doing research on the silviculture of Sierra Nevada forest types, with headquarters at Redding, Calif. Native of Oxnard, Calif., he was educated at the University of California, Berkeley (B.S. in forestry, 1939), and joined the U.S. Forest Service in 1940. He became a member of the Station's research staff in 1946.

True firs make up about one-fourth of the commercial sawtimber in California, and contribute about the same proportion of growth (Oswald and Hornibrook 1966). Yet research on them has been fragmentary to date—often incidental to studies of other species. In California, the most important species of true firs are white fir *(Abies concolor* [Gord. and Glend.] Lindl.*)*, California red fir *(A. magnifica* A. Murr.*)*, and a variety of the latter—Shasta red fir *(A. magnifica* var. *shastensis* Lemm.*)*. For many years, forest managers considered these species "weeds," or at best, "less desirable." And until recently, these species were rated low in stumpage value—mainly because of trade customs, inherent characteristics of their wood, general lumber demand, and in the case of red fir, their relative inaccessibility.

But now that their stumpage value is on a general upswing, foresters are beginning to re-evaluate the worth of white and red fir. No longer are these species to be considered merely as a source of timber—they now have other values. Their location makes their culture increasingly important. Either white or red fir or both grow on some of California's prime mountain recreation areas. And red fir is one of the most prominent trees growing in the State's high-elevation snow belt. The need for an adequate water supply requires that intensive multiple-use management be practiced there.

The condition of stands of residual merchantable fir trees and natural regeneration varies widely because of different cutting practices in the past. I have seen numerous fir stands in selection cuttings, usually heavy, that were damaged by wind soon after initial harvesting. Conversely, similar stands elsewhere have scarcely been affected by wind. Early-day selection cutting and fire exclusion in the "mixed conifer type" (Type 243, Ponderosa pine-sugar pine-fir, Society of American Foresters 1962) favored white fir understory and the establishment of new fir seedlings. But this cutting practice hindered pine reproduction (Dunning 1923).

The results of large clearcuttings in dense mature fir stands have been mixed. In some instances, these stands have regenerated naturally (Gratkowski 1958; Stein 1954), but many large clearcuttings have not regenerated.[1] And the current trend is toward drastically reducing the size of clearcut openings.

To gather more specific information useful in management of true firs, the Pacific Southwest Forest and Range Experiment Station began a series of studies in 1958 at the Swain Mountain Experimental Forest in northeastern California. The research included studies of several factors that affect establishment of natural seedlings after logging. This paper reports results of these and other studies, outlines tentative recommendations for cutting, and considers other factors related to natural regeneration of white fir and red fir.

Any measure of regeneration success at Swain Mountain does not necessarily mean that the same results can be expected elsewhere. And we are not arguing clearcutting as an always preferable method for harvesting dense old-growth stands to prepare sites for natural regeneration. Forest managers should be able to decide on the best silvicultural treatment for their specific purposes by considering (a) results reported here, (b) variations in stand structure within the natural forest, and (c) past happenings on local cutovers and burns. Their specific purposes may be to produce wood, protect scenic values, or integrate cuttings with snow management. As additional research and field experience yield new findings, they will be able to make even sounder choices.

STUDIES AT SWAIN MOUNTAIN

Study Site

Swain Mountain Experimental Forest lies at the southern limit of the Cascade Range, at 5,700 to 7,054 feet elevation, about 10 miles north of Lake Almanor, California. The forest cover is essentially pure fir, with white fir (Type 211, Soc. Amer. Foresters 1962) predominating at the lower elevations. Near the top of Swain Mountain, red fir (Type 207, Soc. Amer. Foresters 1962) becomes the exclusive species.

Swain Mountain is a volcanic cone, with slopes averaging about 10 to 15 percent. Soil is derived from vesicular andesite, and is generally 3 to 8 feet deep. Rocks vary in size and constitute varying proportions of the soil mass.

[1]Gordon, Donald T. *Report of an examination of true fir regeneration on cutting areas in northern California and southwestern Oregon.* 1964. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Redding, Calif.)

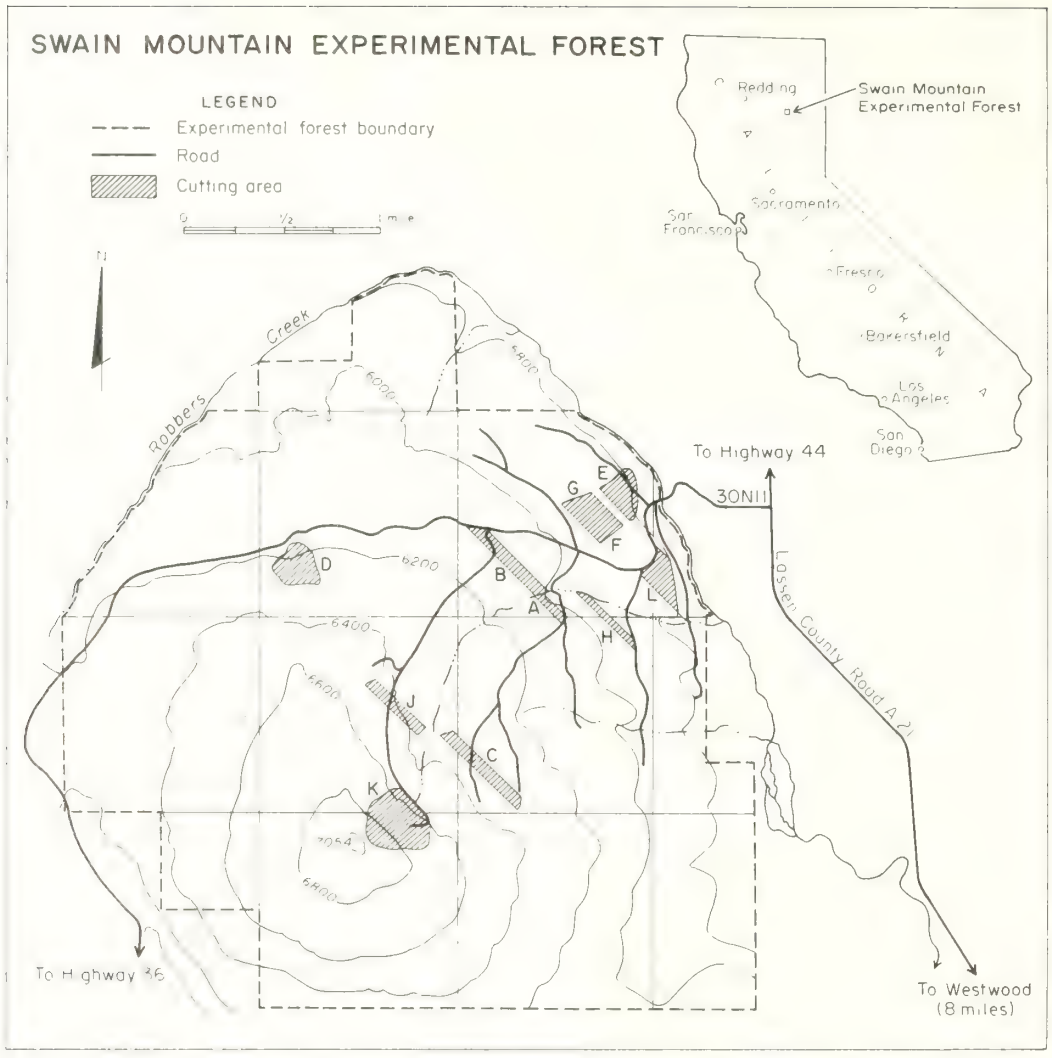

Figure 1.–*Swain Mountain Experimental Forest, northeastern California, where cutting areas were developed in 1958-60. Seedlings and seed were sampled in areas* A *through* D. *Most supplemental studies were in areas* B *and* E.

Precipitation falls mainly as snow. Monthly surveys during four winters revealed that maximum snow depths were between 8 and 10 feet. Forty to 50 inches of water equivalent a year have usually been recorded since the winter of 1957-58. Summers are dry except for occasional scattered thunder showers.

Stand structure varies widely. Volumes over 147,000 board feet per acre (Scribner) have been recorded for commonly-occurring dense stands of mature and overmature trees. Such dense stands have no understory. Less dense stands with volumes of 60,000 to 80,000 board feet per acre are more prevalent, and have abundant fir understories. Most of the Experimental Forest is classed as Site II (Dunning 1942).

General Approach

When these studies were first started, little information was available to guide us. Both white and red fir appeared to be manageable either in uneven-aged or even-aged stands. Management of even-aged stands was studied first.[2] A single set of observations on the Klamath National Forest indicated that red fir clearcut strips with width not exceeding twice the height of border trees (5 chains wide or less) should become

[2]Hallin, William E. *Plan for operation of Swain Mountain Experimental Forest –true fir type.* 1956. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Redding, Calif.)

regenerated naturally. Potential damage by wind was thought to be minimized by limiting strip width to this proportion.

Accordingly, a clearcutting program was begun in 1958. During a 3-year sale, several 3- and 5-chain wide strips and some irregularly-shaped blocks (up to 40 acres in size) were cut. Strips were cut in dense stands with little or no understory. Most blocks were cut in stands where decadent overstory had resulted in a bountiful understory. The blocks were cut primarily to provide opportunities to observe release phenomena rather than to secure new regeneration.

Before any strip was cut, the pre-determined area for its location was surveyed for windfalls. In every case, we found that wind from the southwest quadrant had caused most past damage. All strips were therefore oriented northwest-southeast, so that winds would be least damaging.

The main studies were made on or adjacent to four clearcuttings *(fig. 1)*: a 3-chain wide strip (A) cut in 1958, two 5-chain wide strips (B cut in 1958, C cut in 1959), and on an irregularly-shaped 17-acre block (D) cut in 1958. Research had to be cut back when the first sale was finished. Therefore all studies were confined to the north and northeast slopes of the mountain.

Plans for early studies were influenced strongly by the urgent need for elementary information about true fir regeneration, and particularly those aspects of it which could be influenced most directly by future management practices. In 1959, three studies of regeneration were started. They concerned (a) cone and seed production; (b) seed dispersal; (c) other factors affecting seedling establishment and mortality, including condition of seedbed, competition from all sources, species, distance from cutting edges, causes of mortality, and unusual events.

Field observations for the cone and seed production study were within uncut stands immediately adjacent to clearcut strips A and B. Seed traps for the dispersal study were placed in and adjacent to cutting areas A through D. For the study of factors affecting seedling establishment and mortality, we used a sampling system of adjoining milacre plots in transects oriented northeast-southwest.[3] These transects were installed in each of three slash treatments on clearcut strips A through C. A single long transect was installed in the clearcut block (D), where slash was not treated.

Observations on transects began early in the summer of the year following logging. All milacres were examined annually through 1965, usually in September, except in 1962, when the "Columbus Day Storm" (October 12) prevented further field work that year.

Analyses were made as if data were from a completely random set of plots. We recognized this procedure as a potential source of statistical difficulty.

As work progressed, newly-found leads were studied. Some of these studies were concerned with: amount of insolation at ground level in openings and under crown canopy; soil surface temperature; shade effects on first-year seedlings; and determination of causes of seedling mortality on some selected milacres.

MAJOR FACTORS IN REGENERATION

Seed Production

Methods

An understanding of the factors affecting potential supply of sound seed provides the forester a powerful tool in fostering natural regeneration. Even so, much needs to be learned before we can exert more positive control of sound seed production. Probably the greatest potential lies in learning to control insect depredations.

During summer of 1960, we chose 20 white fir and 20 red fir trees adjacent to clearcut strips for a cone counting study. Only mature trees with non-defective crowns within the upper canopy were selected. Such trees presumably would furnish the most seed for any natural regeneration method. Sample trees were 165 to 200 feet tall, and cones are borne only near the tops. Cones were counted annually by one of two methods, both based on observations from permanently staked points. In years of light cone production, counts were made in the field by using tripod-mounted binoculars. When cones were numerous, a telephoto counting technique (Gordon 1962) was especially advantageous. This method was based on projection-screen counts of cones in tree tops photographed with a 400-mm. telephoto lense. An

[3] I acknowledge the work of David C. Maul, now with the U.S. Forest Service, California Regional Office, San Francisco, in the early design and installation of the milacre sampling system from which parts of the reported data were derived.

appropriate conversion factor transformed these counts into binocular count equivalence. Only "seen cone" data are reported in this paper; no factor is used to estimate unseen cones.

During each year that they were available, several cones of each species were shot down from other than permanent sample trees, or obtained from fresh squirrel-cuttings. Each cone was completely dissected. Seeds were cut, examined, and tallied as sound, unsound, or insect-infested. To be judged sound, a seed had to have both female gametophyte and visible embryo. Insect damage in the form of larvae, larval holes, and feces was easy to identify.

One purpose in this study was to learn how many seeds are produced in each cone. All "seeds" were counted—even those having very small wings—some not over one-eighth inch long. Small "seeds" of this kind would be separated and culled in commercial seed-cleaning operations.

Damage caused by wind and insects reduced to 15 the number of white fir trees on which cones were counted. Three red firs also were lost. Data on two additional red firs were randomly eliminated so that the two species could be compared.

Results and Discussion

Individual white fir trees tended to produce cones at a consistently high, medium, or low level whenever there was a crop. Individual red firs followed an irregular production pattern.

White firs produced more cones than red firs during the study *(fig. 2)*, but red fir cones contained twice as many seeds as white fir cones—on the average, 591 vs. 295 *(table 1)*. However, percent of seed sound was greater for white fir (31 percent) than for red fir (7 percent). During the study period, white fir produced 3.7 times as many sound seed per tree as did red fir *(table 2)*.

A greater proportion of seed of both species is sound during years of abundant seed production *(table 3)*. Conversely, insects tend to damage proportionately more seed when crops are scanty.

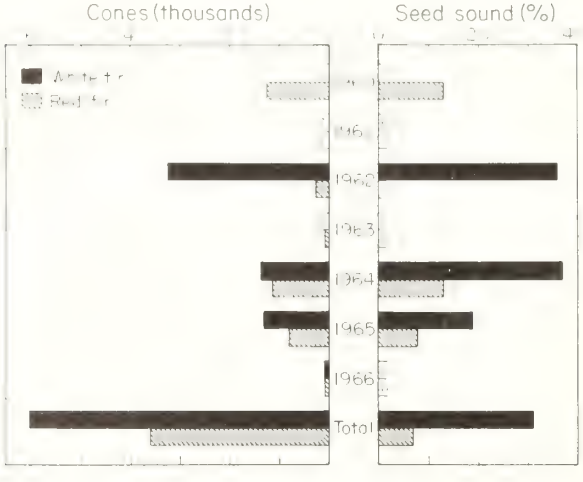

Figure 2.—*White firs produced more cones than red firs, and had a higher percentage of seed sound. Cone production in 15 trees of each species was counted from 1960-1966.*

Table 1.— *Number of seeds per cone, white and red fir, 1960–1965*

Species and seed production	1960	1961	1962	1963	1964	1965	All years
White fir:							
Low	–	–	268	–	312	183	–
Mean	–	–	283	–	339	282	295
High	–	–	308	–	386	403	–
Basis: number of cones	–	–	5	–	3	6	–
Red Fir:							
Low	367	–	428	645	553	372	–
Mean	556	–	532	729	641	553	591
High	688	–	631	795	689	623	–
Basis: number of cones	18	–	5	8	3	9	–

Table 2.— *Average total number of visible cones and sound seed produced per tree during a 6-year period (1960–1965)*

Species	Cones	Total seed[1]	Sound seed[2]
	Number		
White fir	396	116,820	36,214
Red Fir	235	138,885	9,722

Basis: 15 trees, each species.
[1]Based on average number of seeds per cone.
[2]Based on average percent of seed sound.

We have not tallied cone production long enough to determine with certainty if there is any cyclic arrangement of "bumper" seed crops *(table 3; fig. 2)*. Rather erratic cone and seed production is evident; other data reinforce this conclusion. Heavy seed fall of both species occurred in 1956. In 1957, the cone crop was definitely smaller than in the preceding year, but seed was reported as being "abundant" (McKeever 1961). Only nine fir seedlings were found on 493 regeneration milacres on three clearcuttings in the early summer of 1959, indicating a minimum seed crop in 1958. No cones were produced in 1959.

Table 3. *Annual cone production index*[1] *and proportions of sound, insect-damaged, and unsound seed,*[2] *1960–1966*

	1960		1961		1962		1963		1964		1965		1966	
	WF[3]	RF[3]	WF	RF	WF	RF	WF	RF	WF	RF	WF	RF	WF	RF
Cone production index	0	1.00	0	0	1.00	0.21	0	0.06	0.43	0.90	0.40	0.64	0.03	0.05
	Percent													
Sound seed	-	13	–	–	36	2		0	37	13	19	8	-	–
Insect-damaged seed		28	-		6	45		25	31	18	38	42		
Unsound seed		59	-		58	53		75	32	69	43	50		
Total	—	100	-	-	100	100	—	100	100	100	100	100	—	—

[1]Index computed for each species by dividing each year's total cones on 15 trees by number of cones in the most productive year.
[2]All "seed" included; e.g., 1960 red fir data in this table based on 10,009 seeds, not 8,538.
[3]WF = white fir; RF = red fir.

Each year of medium or better cone production during an 11-year period is indicated by an "X" in this tabulation:

Year	White fir	Red fir
1956	X	X
1957	X	X
1958	–	–
1959	–	–
1960	–	X
1961	–	–
1962	X	–
1963	–	–
1964	X	X
1965	X	X
1966	–	–

The cone crop information emphasizes that seed crops cannot always be counted on to recarpet regeneration areas with a flush of seedlings immediately after harvesting. In some locations, including Swain Mountain, some delay is not serious. But where aggressive competitive low vegetation can be anticipated immediately after logging, artificial seeding or planting and other cultural measures may be necessary if the sites are to be held by true firs.

Insects which damage true fir cones and seed were found to be numerous and active. Station entomologists identified the following species from Swain Mountain:

Cone moths:
Laspeyresia (sp.) (Prob. *bracteatana* [Fern.])
Barbara siskiyouana (Kearf.)

Cone maggots:
Hylemya (sp.)
Earomyia (sp.)

Cone midges (Itonididae):
(two spp.)

Seed chalcids:
Megastigmus pinus (Parfitt)
M. rafni (Hoffmeyer).

That control of seed-damaging insects could materially increase the amount of available sound seed is demonstrated by data from the 1960 red fir cone crop. Percent of seed sound was at its highest level for the species that year. Eighteen cones, containing a total of 10,009 seeds, were examined. By deducting 1,471 unsound small seeds found in cone ends, the net total became 8,538. Of these, 15 percent were sound and 33 percent were insect damaged. Complete insect control in this instance could have tripled the amount of sound seed available.

Seed Dispersal

Methods

The influence of seed-bearing trees on ultimate establishment of natural regeneration on a given area will be related to aerodynamic characteristics of the seed, wind direction and velocity, and the number, height, and direction of the seed trees from the area.

Seed dispersal in clearcut areas and in the uncut borders was measured by seed traps. To get a small sample of the heavy seed crop of 1956, large (8.2 sq. ft.) seed traps were placed in two openings created by road construction. The traps were the same type used by Fowells and Schubert (1956). Twenty-five traps were placed in one stand opening, 13 in another. These irregularly-shaped openings were from 100 to 135 feet across.

Seed fall was sampled in more detail in 1960, 1962, and 1964 with smaller traps. The traps were built of steel baking pans 2.5 inches deep and 10 by 14 inches in area (0.9722 square foot). Holes in the bottom provided drainage. A stiff screen with wires spaced 1/3 by 1 inch covered the top. The traps withstood heavy snow loads very well. No evidence of rodent entry was ever seen. Presumably, these traps did a sampling job as effective as one-foot square

traps, and, in addition, sampled seed fall as well as 8.2-square-foot traps (Roy 1959).

These small traps were placed at half-chain intervals across clearcut openings, one foot from the edge of milacre regeneration transects. Long axes of traps were always oriented NW-SE for uniformity. Both ends of the seed trap lines extended for at least one chain into uncut timber.

Seed fall usually began about October 15, so traps were placed before that time. Traps were left in place over winter to catch seed which fell onto the snow and settled into the traps as the snow pack melted. Seeds were sorted from the litter material and cut to determine the amount of sound, unsound, and insect-damaged seed—using the same criteria as in the seed production study.

Results and Discussion

In 1956, on the opening holding 25 traps, an estimated 497,876 sound seed per acre fell. This amount was 39 percent of the total seed catch. On the area holding 13 traps, the sound seed estimate was 440,716 per acre, constituting 40 percent of the total seed. The percent of seed sound shown here should not be compared directly with that reported in the remainder of this section or in the preceding section on seed production. During examination of 1956 seed trap catches, very small "seeds" were not counted as they were in later observations. Therefore, the sound seed percents just cited are higher than they would be if later criteria had been used.

The amount of seed falling on clearcut areas varied with (a) distance from cutting edge, (b) general level of seed production, and (c) specific cutting area *(fig. 3)*.

The variability of seed fall with source distance could be anticipated because of the known aerodynamic characteristics of fir seed (Siggins 1933), and with year because of the irregularity of most coniferous seed crops. When studies began, little was known of the influence of stand density, tree age, or other conditions near uncut edges, on the levels of seed fall within clearcuttings.

One might suppose that relative level of seed fall on clearcuttings would vary directly with density of mature seed-producing trees in the timbered borders. But we gained little information by mapping stand structure and species composition for the timbered strip along uncut edges. The only obvious observation is that low density of seed-bearing trees on the southwest side of Cutting Area C probably accounts for the relatively lower seed fall there *(fig. 3)*. All other relationships of seed fall rate and stand structure are obscure.

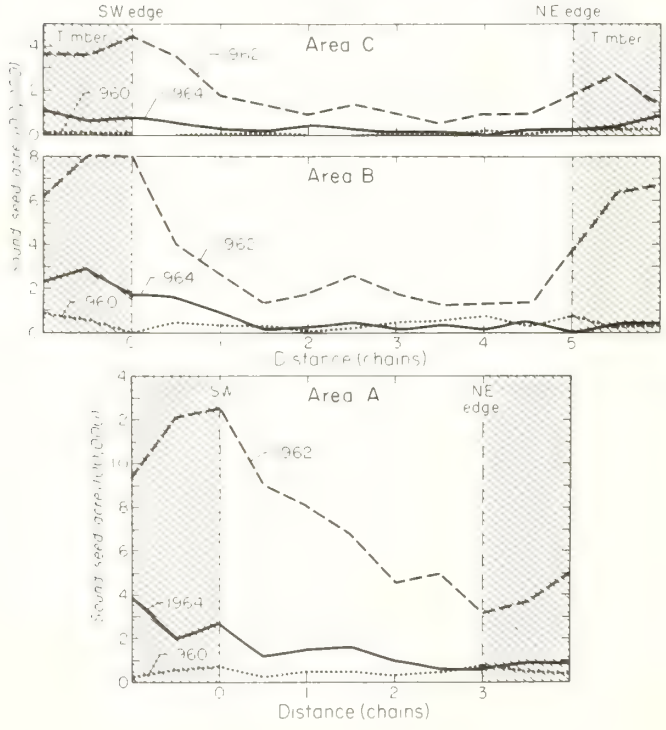

Figure 3.—*Amount of sound seed per acre which fell at various distances from edges of 5-chain- and 3-chain-wide clearcut strips during 3 different years. Each line was plotted from data derived by averaging records of three seed-sample transects.*

Orientation of cutting strips at right angles to the prevailing wind resulted in much heavier seed fall at the southwest than on the northeast sides of areas in 1962 and 1964. Irregular air currents apparently were responsible for the light seed distribution from the northeast edges into the strips. Sound seed fall in 1960 was so light that the observed results merit little credence.

A significant portion of seed produced by the northeast cutting edges in 1962 and 1964 was blown back under the uncut canopy, where it was not needed. This observation is further emphasized by ungraphed data from extensions of some seed sampling lines further northeast into uncut timber.

Seed dispersal over openings seems to be determined largely by amounts released at the windward cutting edge *(figs. 3,4).* Seed fall within narrow openings generally is higher than within wide ones *(fig. 3,* Cutting Area A vs. B; *fig. 4).* Wind eddies may influence seed dispersal much as they do snow deposition.

Both prevailing and strong storm winds blow from the southwest at Swain Mountain. Only occasionally has any significant amount of seed fallen there before October 15, and before the fall storms. And fir cones do not shatter as readily when wet as when dry. This means that much seed falls during winter months (a) in dry periods between storms, (b) when cones are damp and wind velocities are high, (c) as a result of the cone-shattering effect of heavy snow loads, or (d) freezing-thawing. Therefore, varying amounts of seed fall to the ground or upon snow, depending upon whether early precipitation has been rain or snow. Additionally, distance of seed flight is inhibited whenever moisture content of seed is increased by precipitation, since the ratio of seed weight to wing area is increased. A late, dry fall with periodic strong winds is ideal for good seed dispersal.

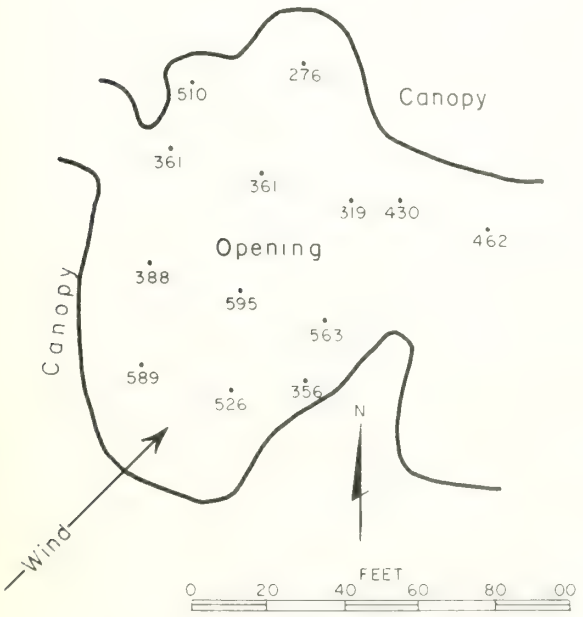

Figure 4.—*Sound seedfall in 1956 in a small opening. Numbers are thousand seeds per acre.*

Show[4] has offered a possible clue to explaining abundant regeneration at seemingly great distances from seed source. In an unpublished report, he wrote: "This winter, much to my surprise, I found that the Yellow and Jeffrey pines retained many unopened cones until well along in February, and it can readily be seen that the seed, falling on the snow, (which is packed and smooth at that time of year) may readily travel considerable distances, especially if on a steep slope or exposed to wind." Fir seeds might be dispersed in this manner, but a special sequence of weather conditions would be necessary.

Germination

The earliest time of year when white fir seeds were seen germinating was February, in 1963, at an elevation of 5,700 feet, about 8 miles northeast of the Swain Mountain study areas. Wherever there were patches of bare ground, either in bright sunlight or deep shade, radicles had extended as much as 1/4-inch from the seed coat. Snowdrifts were not examined for germinating seedlings.

Seedlings were studied in detail at Swain Mountain in 1963 at weekly intervals from June 19 until October 28. Date of final snow melt in the spring was irregular over the areas examined, but was complete about June 12. Seed germination was complete by July 8. Only five percent of germinant seedlings were found between June 19 and July 8.

At Swain Mountain, both white and red fir seed have been found germinated on, in, and beneath snow. Noble fir *(A. procera* Rehd.*)* and Pacific silver fir *(A. amabilis* (Dougl.) Forbes*)* have been reported to germinate on snow (Stein 1951). Franklin and Krueger (1968) recently reported that Shasta red fir, subalpine fir *(A. lasiocarpa* (Hook.) Nutt.*),* and grand fir *(A. grandis* (Dougl.) Lindl.*)* germinate on and in the snowpack.

Many potential seedlings die because of the characteristic of germinating within the snowpack. Pri-

[4]Show, S. B. *Natural reforestation of brushfields.* 1913. (Unpublished rep. on file at Pacific SW. Forest & Range Exp. Sta, U.S. Forest Service, Redding, Calif.)

mary rootlets sometimes reach a length of 2 to 3 inches within the snow. When the snow melts, many of these rootlets dry, or are killed by heat, before their tips turn into the ground. On June 19, 1963, for example, 136 seedlings were found on a milacre plot. Of these, 30 were erect and normal-appearing, 14 had been killed by cutworms, and 92 (68 percent) were lying flat on the ground, dead, with dry rootlets.

An incident reinforcing observations of the waste of fir seed falling onto snow follows: abundant seedlings for a special study were wanted in the center of an eight-acre clearcut (E, *fig. 1).* In 1964, white fir seed was gathered locally and rough cleaned. About 10 pounds (a minimum of 82,000 seeds) were available, and a cutting test indicated that the seed was 54 percent sound. Unfortunately, the first snowfall on the area measured 22 inches. Seedlings were needed badly next spring, so all the seed were sowed on the snow over an area about 20 feet wide and 5 chains long. Next spring, only slightly more than 200 seedlings were found during a diligent search—indicating a maximum seed effectiveness of about 0.4 percent. The ground was littered with dead, germinated seeds. Seedlings on other parts of the area were practically non-existent, so natural seedlings did not affect the observed results. We can deduce that artificial seed sowing on snow will never be efficient.

Apparently, red and white fir seeds begin to germinate in the woods after three conditions have been met: (1) absorption of sufficient water, (2) exposure to an undetermined degree and period of low temperature, followed by (3) exposure to a period of higher temperature favoring germination. A period of cold seems necessary because no germinated seeds were ever seen before permanent snow pack was in place—even though in some years seeds had been well-wetted during fall. The period of favorable "higher" temperature mentioned may very well be close to 32°F. Observation of germination in both February and June seems to rule out length of day as a significant factor.

Field identification of seedlings often is desired soon after germination. Only meager notes on the subject can be given here. When red fir and white fir seedlings are growing together, I have not always been able to identify positively the species during the first few weeks of establishment. The largest seedlings definitely are red fir, and the smallest usually are white fir, but sizes overlap. Color shades of stems and cotyledons, and numbers of cotyledons, apparently intergrade. Some rather minute differences, visible for the most part only with a 10X hand lens, seem to exist between species, but these need further checking. In practice, species were recorded on the basis of the best evidence available; wherever errors later became apparent, records were changed.

Seedbed Condition

Work of numerous foresters with many species in the past has indicated the positive advantage of particular kinds of seedbeds for seedling establishment. We found that a mineral soil seedbed, easily created by machinery, has an edge over other kinds.

Methods

To compare effects of different seedbed conditions on seedling establishment, we treated slash on each clearcut strip three ways: no treatment, lopping and scattering, and bulldozing into piles to bare as much mineral soil as possible. Each treatment was intended to create a substantially different seedbed. And each was sampled by at least one continuous transect of milacres on each cutting area.

Seedbed condition of each milacre was recorded during each annual examination. A classification was not changed except when a well-defined shift occurred. Two major surface categories were recognized: (1) potential seedbed, and (2) physical obstructions to seedling establishment, such as stumps and rocks.

Potential seedbed surfaces were described by these terms:

Mineral Soil:

Bare soil or soil with very minor amounts of organic material on the surface or in mixture.

Litter:

Light: Uniform distribution of needles or small twigs over entire surface, but mineral soil visible, or, small patches of medium litter with mineral soil visible between patches.

Medium: Uniform distribution of needles or small twigs to about 1/4-inch depth, or, small patches of heavy litter with mineral soil visible between patches.

Heavy: Needles and small twigs usually 1/4- to 3/4-inch deep, but also deeper, generally in a compact mat, little or no mineral soil visible.

Slash:

Light: Small pieces of slash covering less than 30 percent of surface.

Medium: Any size slash covering 30 to 60 percent of surface.

Heavy: Any size slash covering over 60 percent of surface.

Mineral soil was an exclusive surface class; litter and slash were not exclusive. A given milacre could

receive a classification such as "medium litter," or "light litter and heavy slash." Sixteen classifications of seedbed surfaces were possible.

Obstructions to seedling establishment were recorded as to type, and proportionate area of the milacre they occupied, by 10 percent classes. Objects judged physical obstructions included stumps, large rocks, large cull logs, and deep piles of debris (litter and slash).

The number of possible seedbed classifications was too large to permit reasonable statistical comparisons. After preliminary analyses, five seedbed classes were used for evaluation of chosen variables:

	Description of Class[1]	
	Litter	Slash
Seedbed class:		
Mineral soil	O	O
Light litter and slash	L	O or L
Slash	O	L, M, or H
Heavy litter	M or H	O
Heavy litter and slash	L, M, or H	L, M, or H[2]

[1]Symbols: L=light, M=medium; H=heavy; and O=none.
[2]Except for the combination of light litter and light slash.

Slope and aspect of each milacre were recorded. Neither aspect nor slope was used in any analysis because all aspects were in the northeast quadrant, and all slopes were gentle—seldom exceeding 10 percent.

In addition, an irregularly-shaped 8-acre block (E, *fig. 1*), where slash was heavy, was examined for regeneration from time to time. Essentially no seedlings were seen on it through 1964. In fall of 1964, slash was broadcast burned to prepare the area to receive a seed crop.

For preliminary statistical comparisons, strip cutting areas were grouped by year of treatment, which was the same as year of cut. This division avoided confounding by year of treatment, personnel, equipment usage, and rate of decay of organic matter. Slash treatments were compared, as were the distributions of seedbed conditions within slash treatments. Analyses showed that distributions of seedbed classes were different among slash treatments for both year-of-treatment groups, and at both initial and final examinations.

Results and Discussion

Bulldozer slash clearing produced more milacres with mineral soil, or light litter and slash than other treatments *(table 4)*.

During the study, the number of milacres having bare mineral soil increased. The trend became apparent 3 and 4 years after the study began. This increase was accompanied by changes in other seedbed classifications from relatively heavy to lighter amounts of organic material *(fig. 5)*.

On cutting areas treated in 1958, changes from

Table 4—*Seedbed condition, by slash treatment, at first and last examinations, in clearcut strips*

Slash treatment and year examined		Seedbed condition classes					
		Mineral soil	Light litter and slash	Slash	Heavy litter	Heavy litter and slash	Milacres
		Percent of milacres					*No.*
		TREATED IN 1958					
None:	1959	12	11	5	22	50	110
	1965	18	6	4	20	52	110
Lop and scatter:	1959	6	5	26	12	51	110
	1965	11	3	22	11	53	110
Bulldozer slash clearing:	1959	27	22	16	27	8	103
	1965	46	10	11	22	11	103
		TREATED IN 1959					
None:	1960	18	12	4	22	44	50
	1965	20	12	4	22	42	50
Lop and scatter:	1960	0	8	6	18	68	50
	1965	0	8	6	20	66	50
Bulldozer slash clearing:	1960	18	14	0	54	14	50
	1965	40	16	0	30	14	50

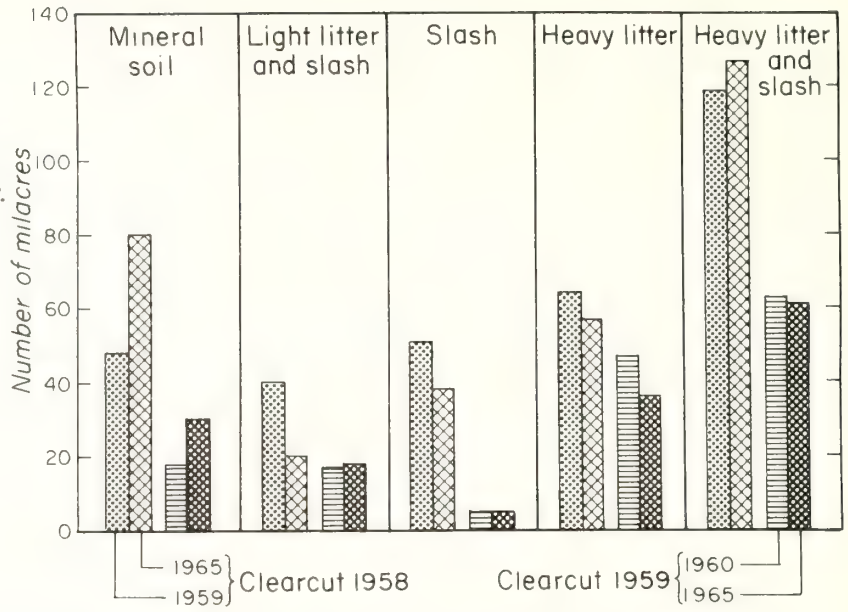

Figure 5.—*Comparison of number of milacres in each of five seedbed classes at first and last examinations.*

one seedbed class to another were highly significant during a 6-year period. Changes on the area treated in 1959, which was observed for 5 years, were not significant. These reasons may account for observed changes:

- Lack of overstory to contribute new litter fall,
- Disappearance of organic fines through decay,
- Animal trampling (simple scattering, or mixing with mineral soil),
- Bark slabs sloughing from large cull logs,
- Parts of wind-damaged tree crowns falling to the ground (near cutting edges).

Soil compaction from logging, clearing, or weight of snow pack was not a problem on clearcut areas studied. No comparative physical measurements of compaction were made, but soils were loose and drained well. Erosion was not a problem on the gentle slopes.

Experience with the milacre as a unit of area on which to rate certain surface characteristics was not completely satisfactory. Microsite observations of seedling environments might have led to more meaningful conclusions about seedling establishment.

On the 8-acre block (cut in 1959), litter and slash were so uniformly heavy that essentially no seedlings became established through 1964. A fairly good seed crop was apparent in 1964, so slash was broadcast burned in late autumn to prepare a better seedbed. Burning was accomplished before rain or snowfall, and an exceptionally good cleanup resulted *(fig. 6).* Unfortunately, this treatment also stimulated germination of abundant seeds of mountain whitethorn ceanothus *(Ceanothus cordulatus* Kell.*).* By fall, 1965, new fir seedlings were rare beyond a chain from cutting edges, indicating poor seed dispersal the preceding year. The part of the area without seedlings was planted in spring of 1966.

In treating true fir slash, certain problems—some peculiar to fir—become apparent. At the end of summer in which fir slash has been created, large pieces of the slash are still wet, and much of the fine material—needles and branch tips—is resistant to fire. At a certain stage in drying, needles and small twigs, particularly of red fir, often will not continue to burn when held in the air and lit with a match. A few burning trials in the year of felling were unsuccessful. Not enough slash in piles and windrows was consumed. Where slash is to be burned, a delay of 1 or 2 years after logging would insure destruction of more material. Although there may be certain dangers in letting slash accumulate for several years (burning load, insect buildup, etc.), certain advantages might be gained. If properly timed, delayed slash burning might create vegetation-free mineral soil seedbeds shortly before a good seed fall. At the same time, fire might stimulate germination of brush or other seeds which otherwise would have remained dormant.

Bulldozers were used for most slash-clearing operations at Swain Mountain. No comparative costs are available, but we know that slash clearing on fir clearcuttings was more expensive than in regeneration clearings in the ponderosa-Jeffrey pine type in northeastern California. In the fir forest, numerous large stumps and cull logs increased the cost of seedbed preparation. Seedbed preparation with tractors in selection or shelterwood cuttings would require extra care to avoid damage to residual trees.

Figure 6.–*Before,* top, *and after,* bottom, *burning slash on portion of logged area which was typical of medium density overstory with generally sparse mixed-size understory.*

Soil Surface Temperature

At many places in a true fir forest, temperature of the soil surface reaches heights lethal to new seedlings. Intensity and duration of solar radiation, ambient air temperature, character of soil surface, and soil moisture all influence soil surface temperature.

Methods

Observation of a 170°F. temperature in deep litter at Swain Mountain led to study of surface temperatures in various seedbeds and the related seedling mortality. Baker (1929) suggested that a 130°F. temperature could kill western conifer seedlings.

In a preliminary study during summer of 1963, temperature pellets were used to gain data on soil surface temperatures. Many different soil surface conditions were sampled on the milacre transects previously described. Melting points of the pellets were 113, 125, 138, and 150 degrees F. All 138°F. (and those of lower melting thresholds) melted. And most of the 150°F. pellets melted.

In a second study, soil surface temperatures were sampled in standardized media between June 26 and July 30, 1964. Batteries of Tempils having melting points of 125, 138, 150, and 163 degrees F. were placed in mineral soil and in litter 1/4-inch, 1/2-inch, and 1-inch deep at each sampling point. The pellets were placed edgewise into the dry material, so that half the diameter was buried. All sample points were leveled to eliminate effects of slope. For uniformity, fir litter, consisting mainly of dead needles, was carried to sample points from thick deposits beneath a closed stand. This material was "very dark gray," approximating "10 YR 3/1" on the Munsell (1954) soil color charts. The soil was "grayish brown," approximating "10 YR 5/2."

Within a 5-chain wide clearcut strip, sampling points were located as follows *(fig. 7):* on lines parallel to the northwest-southeast oriented cutting edges, three points per line, points 1/2-chain apart; lines of samples were located 1/2, 1-1/2, 2-1/2, 3-1/2, and 4-1/2 chains from the southwest cutting edge. Three sample points were also placed deep within a dense overmature stand nearby, 1/2-chain apart on a northwest-southeast, oriented line. Three more points, spaced 1/2-chain apart and oriented southwest-northeast, were located near the center of a small opening surrounded by over-mature timber.

Results and Discussion

Altogether, 336 Tempils were installed. Of these, 68, or 20.2 percent, were rendered useless, mainly by

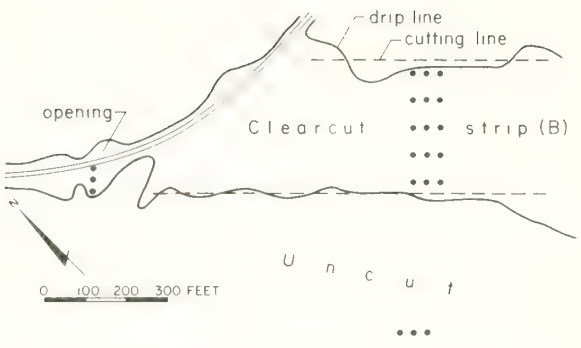

Figure 7.–*Soil temperatures and illumination were measured at sample points within a 5-chain wide clearcut strip, a small opening, and a dense uncut stand.*

rodents, cattle, deer, and possibly jays. Tempils are color-coded by melting points, but pellets of a particular melting point were not disturbed more than any other. Disturbed pellets were excluded from the calculations.

Highlights of this small study are *(table 5):*

- Most points on the soil surface reached a temperature of 150°F.
- There was no apparent relationship between the location of a sampling point and the observed pellet melt. Temperatures reached high levels under dense old stands as well as in large openings. This was probably the most striking result of the study.
- Surface temperatures on mineral soil seldom exceeded 163°F.
- Within the limits tested, surface temperatures tended to increase with litter depth.
- Temperatures which have been presumed lethal to seedlings occurred at nearly every sampling location.

Duration of high ground-surface temperatures was not measured. Melting, sometimes only in hairline traces, is nearly instantaneous whenever the melting point of a Tempil is exceeded. Little can be surmised about the duration of high temperature under intermittent shading, but in unshaded clearcut strips several hours of direct sunlight probably cause sustained high temperatures (see section on Insolation). The relatively poor seedling survival in large clearcuttings compared to that in a small stand opening may be explained, at least in part, by heat duration. Other investigators, particularly Baker (1929) and Silen[5] have suggested that absolute temperature is not necessarily the critical factor responsible for heat damage to seedlings; instead, within relatively broad limits, abundant time-temperature relationships can cause damage.

An additional factor may affect higher initial survival in small openings than in wide clearcuttings (and even under dense old stands). It is the soil or litter surface dampness which remains longer under cover, thereby delaying high temperatures until small seedlings are physiologically more resistant to that hazard.

Table 5.– *Effect of soil surface condition on temperature*

Soil surface condition	Tempil melting points (degrees F.)			
	125	138	150	163
	Percent of pellets unmelted			
Mineral soil	0	0	6.7	88.9
1/4-inch litter	0	0	6.7	46.7
1/2-inch litter	0	0	6.7	50.0
1-inch litter	0	0	.0	15.8

Insolation

Seedling establishment resulting from the seed crops of 1960 and 1962 was best near cutting edges and in small openings, such as road rights-of-way. Dispersal data showed a concentration of seed near its source, and, on 5-chain wide strips, decreasing amounts at greater distances from cutting edges. However, since the firs are tolerant, I hypothesized that shade also might influence initial seedling establishment. On a large proportion of the study areas, unfortunately, shade could be created only by the seed source trees, and duration of shade would be related to distance from them. Therefore, the relative influences of seed dispersal and shade could not be separated within the framework of the sampling system and cost limitation. Consequently, the objectives of a supplemental study were to determine (a) the relative amounts of solar illumination reaching the ground surface under varying conditions of sunlight and shade, (b) maximum solar energy received at the center of a 5-chain wide clearcut strip (B), and (c) effects of shade and sunlight on seedling survival.

Measurements of Insolation

To get near-maximum values of diurnal insolation, two kinds of measurements were made simultaneously on July 8, 1965, about 2 weeks after the

[5]Silen, Roy Ragnar. *Lethal surface temperatures and their interpretation for Douglas-fir.* 1960. (Unpublished Ph.D. thesis on file at Oregon State University, Corvallis.)

summer solstice: (1) a pyrheliograph recorded solar energy all day at the center of the same 5-chain wide clearcut used for the soil surface temperature study, and (2) illumination was concurrently measured at all the sampling points used in the soil temperature study *(fig. 7)*. The benzene-anthracene technique determined amounts of solar illumination at intervals during a day. Analyses of the sample solutions and of the data followed the methods of Waring and Major (1964).

Anthracene in benzene solution is sensitive to the ultra-violet portion of the spectrum, around 300-400 millimicrons wave-length. In this study, then, as in others using the technique, comparative light quality in shade or full sunlight was ignored. Light quality has little effect in ecology of coniferous forests. Logan and Peterson (1964, p. 7) cite several investigators who have reached this conclusion.

The primary purpose of this study was to compare amounts of illumination reaching the forest floor at the different sample points or zones, although indications of quantitative levels of illumination also were of interest.

Glass vials of solution, placed on uniform gray botany blotters during the night preceding exposure, sampled solar illumination. On the day of exposure, one vial from each point was picked up at 9 a.m., 12 N., 3 p.m., 6 p.m., and after dark. Labeled samples were picked up and placed in light-proof boxes in the same sequence each time.

Samples were calibrated by using unexposed vials, and others exposed completely or beneath varying degrees of shade from 10 a.m. to 2 p.m. Illumination on the calibrating vials was measured in foot-candles at 15 minute intervals from 10 a.m. to 2 p.m. with a Weston 603 illumination meter.

Four days after exposure, optical density of the solution in each vial was determined with a Beckman DU spectrophotometer at wave length 360 millimicrons, using a tungsten lamp and a 0.1 mm. slit.

The illumination meter and spectrophotometer used in this study are the same types used by Waring and Major (1964), so illumination data here should be comparable with theirs for California's northwest coast.

Results and Discussion

The day chosen for these studies was ideal—the sky was deep blue and cloudless. The flow of energy through the atmosphere was even, as shown by the shape of the pyrheliograph transcription *(fig. 8)*. Irregularities at both ends of the record were caused by tree shadows. Stands at the cutting edges approached maximum density for white and red fir *(fig. 9)*, yet their small influence on light at the center of this strip was obvious from the measurements.

Maximum energy received on the horizontal sensitive plates of the instrument was 1.60 gram calories per square centimeter per minute. Calculated energy perpendicular to the sun's rays was 1.7 calories—an amount to be compared with the so-called solar constant having average value of 1.95 above the level of the atmosphere (Forsythe 1954). A comparable horizontal plate pyrheliograph record showed a maximum of 1.51 gram calories on a clear day—June 24, 1966—at Redding, California. This city is at almost the same latitude, but at 500 feet elevation.

Measurement of illumination with the benzene-anthracene vials produced generally satisfactory results. In the regression analysis of optical density on percent light, all calibration data fell within 95 percent confidence limits. The coefficient of correlation was -0.9983.

The most striking result of this study is the relationship of total illumination at the edges and center of the wide strip *(fig. 10)*. Total illumination to 6 p.m. at the southwest side was 42,233 foot-candle-hours, which is 82 percent of the 51,367 recorded at the center. The narrow opening received 33,867 foot-candle-hours of illumination, or 66 per-

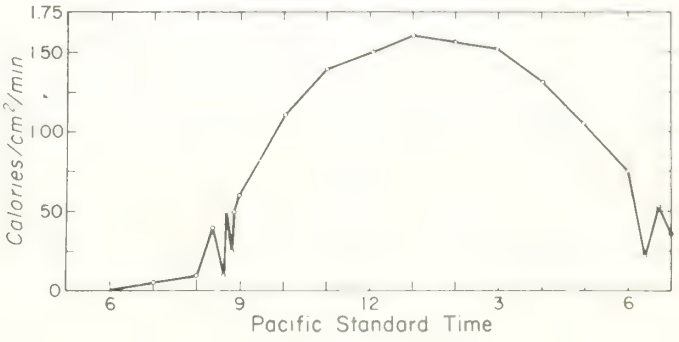

Figure 8.—*Solar energy incident to horizontal plane is shown by a transcript of pyrheliometer recording for July 8, 1965, latitude 40°26'N., longitude 121°05'W., elevation 6,200 feet.*

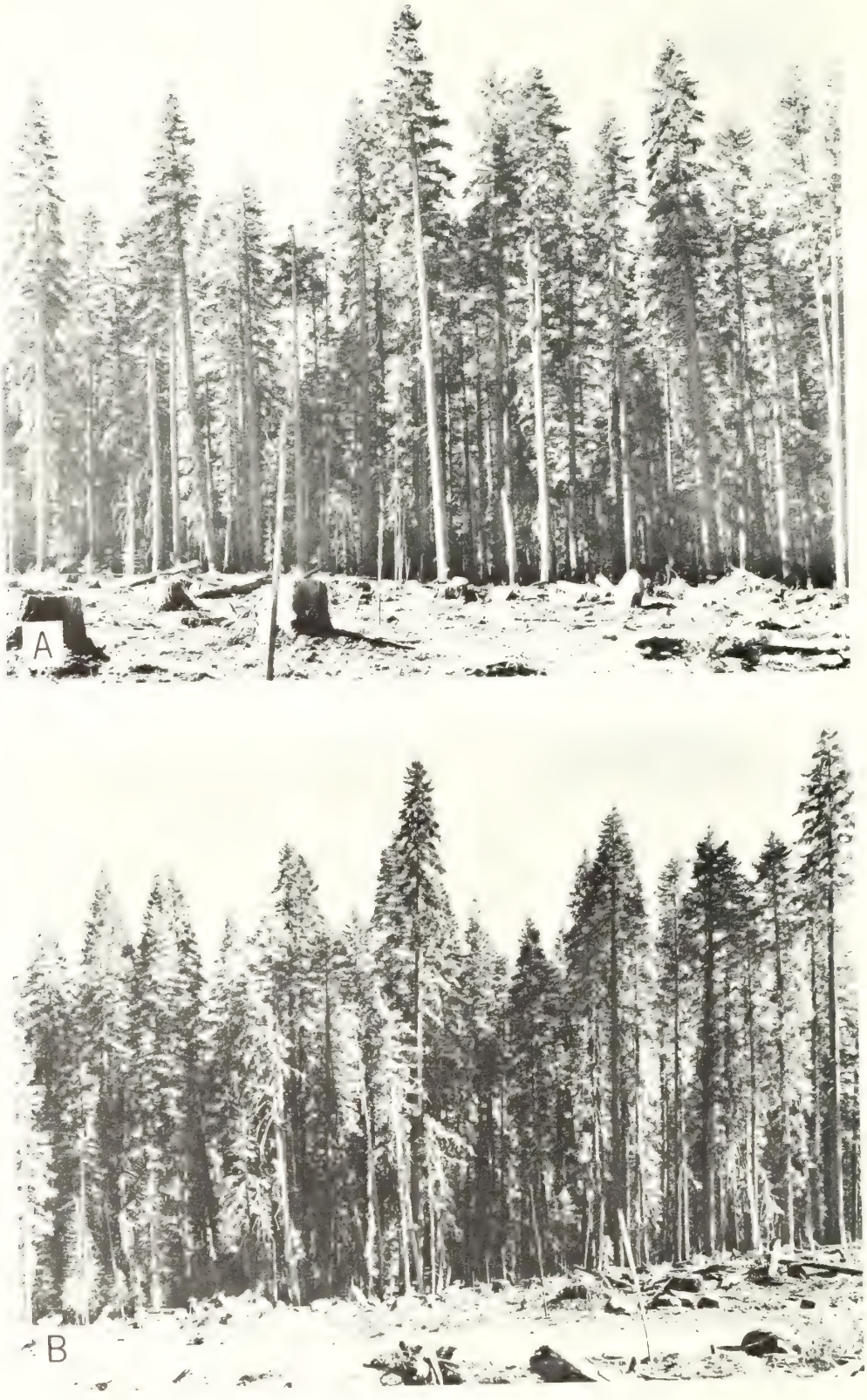

Figure 9.—*Fir stands immediately adjacent to cutting strip sample points shown in figure 7:* A, *southwest edge;* B, *northeast edge.*

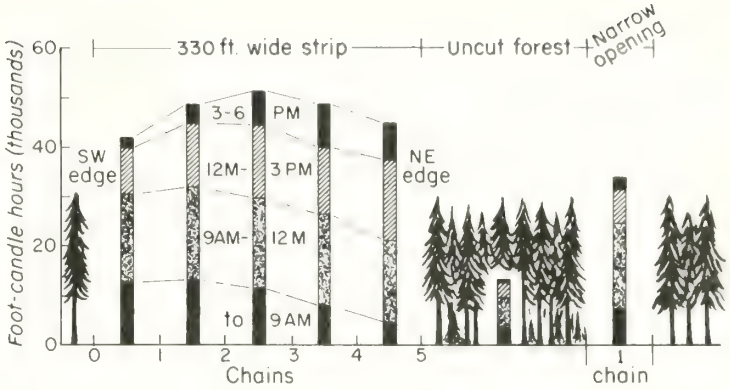

Figure 10.—*Illumination in forest and openings on July 8, 1965, Pacific Standard Time. Segments of bars are additive.*

cent of maximum illumination at the center of the strip. The uncut stand received 13,467 foot-candle-hours or 26 percent of maximum illumination at the center of the strip.

The NW-SE orientation of the 330-foot wide strip naturally contributes to the shape of the histogram of figure 10. The "narrow opening" bar represents a cutting area oriented approximately E-W and is most directly comparable to cumulative insolation at each side of the wide strip.

Results indicate that, for old pure fir stands, our common ocular estimates and shade diagrams for different solar angles at cutting edges lead us to overestimate "shade." Transmission of light through an overmature and heavily stocked fir stand is greater than we thought. We can infer that, where high fir crowns are involved, shade is of appreciable density and duration only near cutting edges of certain orientations. Cutting edges should not be thought of as solid curtains which produce dense shade. This point has been further illustrated through a series of aerial photographs taken at 2-hour intervals during a day (Gordon 1968).

The illumination data show that large clearcuttings of nearly any orientation will have large proportions of soil surface exposed to prolonged sunlight. This can mean long periods of above-lethal soil surface temperature. At the other extreme, single tree or small group harvesting would certainly reduce the time of exposure of seedlings to above-lethal temperatures.

An anomaly in the illumination data is mentioned as a caution to other workers who may contemplate using a similar time-interval technique. Of the total of 21 sample points, 15 had indicated full-day illumination which was equal to or less than cumulative illumination until 6 p.m. Polymerization of insoluble dianthracene is an irreversible reaction, so this process cannot explain the results. Experimental error in the form of leaking vials (which were not seen) or improper use of the spectrophotometer have been suggested as explanations. Yet, of the 84 field exposure samples collected to 6 p.m., only two appear to be out of line. Additionally, of the samples collected after 6 p.m., all those in the uncut stand, and two-thirds of those in the small opening, indicated less exposure than was recorded to 6 p.m. Thus, the riddle is not connected with exposures which might have resulted in solution changes exceeding the readable range of the spectrophotometer, nor with possible inaccuracies at the high foot-candle-hour end of the extrapolated calibration curve. I cannot readily explain the anomaly.

Data to 6 p.m. appear to be logical, and the histogram and general discussion are restricted to them. Data for the 5-chain wide strip were arranged in one analysis as three rows of samples running across the strip. The rows were not statistically different. Therefore, data for each of the bars *(fig. 10)* were obtained by averaging three measurements equidistant from a cutting edge.

Influence of Sunlight and Shade on Seedling Survival

Evidence of the influence of shade on seedling survival at Swain Mountain is limited but impressive. In 1965, shaded and unshaded first-year white fir seedling survival was compared at the center of an eight-acre clearcutting (E, *fig. 1).* Shades were placed a few days after snowpack had melted. Shade was provided by small pieces of sheet metal bent at a 90° angle *(fig. 11).* These sheets shaded the soil surface as well as the seedling stems, and often part or all of the cotyledons and needles. No browse protection was provided. Some browsing and trampling by deer and cattle were observed. By September 30, survival percents were 48.3 for shaded and 1.3 for unshaded seedlings.

If shade close to cutting edges of 3- to 5-chain strips is of some benefit for establishment of natural seedlings, its effect must occur principally within the first growing season. Such shade from large firs appears to have no beneficial effect on seedling

Figure 11.–*Sheet metal shaded the seedlings and the soil surface.*

survival during second and third years of the establishment period *(fig. 12).* The relative rate of seedling loss is greater near edges than at more distant locations. However, edge locations have more seedlings at the end of 3 years.

Since high surface temperatures had been found for deep litter, the influence of natural shade-creating objects on first-year seedling survival in litter accumulations was explored. One analysis concerned milacres covered with heavy litter accumulations, but no slash, and shaded or not shaded by advance reproduction. In this case, 58 percent of the shaded milacres and 36 percent of the unshaded milacres were stocked with new seedlings, and the effect of shade was statistically significant. Another analysis tested the influence of shade cast by various amounts of slash on seedling establishment in heavy litter. In this case, no significant effect was detected.

Stark (1965) reported, quite similarly, that white fir seedlings of different ages survive "best in dense shade with medium litter and on shaded bare soil," and that "white fir survival in heavy litter was greater in shade, an observation evident in many of the dense litter sites."

Seedlings sometimes become established under conditions contrary to those reported as general trends in this paper. I have seen, for example, two instances of abundant Shasta red fir regeneration in completely unshaded situations at great distances from "adequate" seed sources. One site was on the Union Creek District of the Rogue River National Forest in Oregon; the other was a few miles east of Mt. Shasta on the McCloud District of the Shasta-Trinity National Forest in California. In both locations, mineral soil was preponderant seedbed type–the only item of general agreement. Foresters often find themselves wishing for specific data on the total environment during a particular year of germination.

At Swain Mountain, white and red fir have responded similarly to light. And Shasta red fir at other locations appears to regenerate similarly to these two species. Similar response to light may extend even more broadly through the genus. Day (1964) found that subalpine fir *(A. lasiocarpa* [Hook.] Nutt.*)* reproduced more abundantly with increasing density and duration of shade. Vezina and Pech (1964) studied solar radiation in stands of balsam fir *(A. balsamea* [L.] Mill.*).* They found that low solar radiation permitted balsam fir seeds to germinate, but under low radiation, seedlings generally died within a year. This result apparently is not "pure," for they imply that soil moisture conditions could also cause mortality of young seedlings under relatively dense stands. Vins (1964), in reporting on Czech experiments comparing effects of regeneration felling on silver fir *(A. alba* Mill.*),* stated that group felling and strip felling (particularly on the south of the stand) produced the best conditions for regeneration. He also concluded that over-shading is a frequent cause of failure of regeneration. In context,

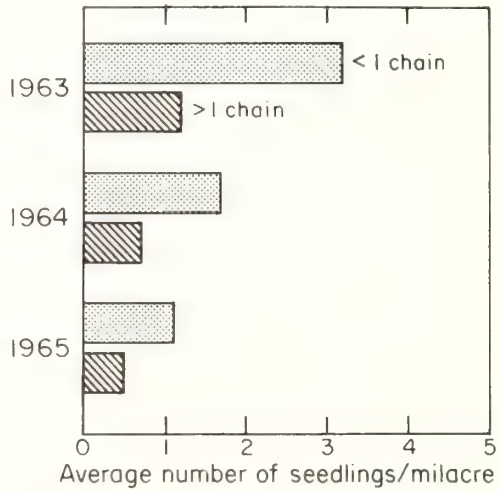

Figure 12.–*Relative abundance of seedlings at distances less or more than 1 chain from edges of clearcut strips, as recorded at end of growing seasons. Seedlings originated in spring 1963.*

this appeared to mean failure over an unstated period of time. Evidence generally indicates shade benefits fir seedling establishment– especially during the first year.

The U.S. Weather Bureau (1964) found that the area dominated by the Sierra Nevada and southern Cascade Range within California receives more daily solar radiation in July than any other part of the United States–700 to 750 langleys (cal/cm.^{2}). We can exert some control over insolation during the critical early period of seedling establishment. The highest ratio of seedlings to seed–efficiency–during the first year or two will result from shade, natural or artificial, combined with optimum levels of other factors.

Soil Moisture

Within a large opening in a fir stand, soil moisture seemed to be available all season at soil depths reached by roots of many new fir seedlings.

Methods

Watershed management personnel determined by neutron probe the soil moisture percent by volume at a number of points in and adjacent to a 5-chain wide strip clearcut (B) at Swain Mountain four times at monthly intervals in 1961. For purposes of this regeneration study, three points each on two of their soil moisture sampling transects were selected because there were no trees near them. The points within the strip were at the center and at half-chain distances from the southwest and northeast cutting edges. Of the data on watershed management soil moisture percent, I have used only that for the potentially most critical depths of 3, 6, and 9 inches. Soil bulk densities, and 15 atmosphere moisture percentages were determined in the laboratory for the same soil depths at a later date.

Results and Discussion

If we assume a 15 atmosphere moisture percentage as the wilting point for firs, seedlings would have had adequate moisture at the 6-inch depth and deeper throughout the summer of 1961 *(fig. 13)*. Differences in moisture percents for wilting points, by stations and depths, probably were caused, at least partially, by the bulldozer operations in slash clearing and road building. The upper soil layers were disturbed to varying degrees, and so may have had artificially differing amounts of organic constituents, and compaction, superimposed on natural variation.

Since primary roots of seedlings germinating in snow reach lengths of 2 or 3 inches, the roots of those germinating at the soil-snow interface may penetrate soil to about the same depth before snow melts completely. We know that some white fir seedling roots will reach lengths of 6-12 inches or more in the first season,[6] and I assume this is true for red fir. Root growth of some first-year white and red fir seedlings begins early enough and progresses rapidly enough under average conditions in the open so that roots continue to have available soil moisture.

Although the soil at Swain Mountain is fine-textured, it is also porous. "Excess" water at time of snow melt percolates through it rapidly. Apparently, moisture is lost slowly from the soil after field capacity has been reached.

[6]Unpublished data on file at Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Redding, Calif.

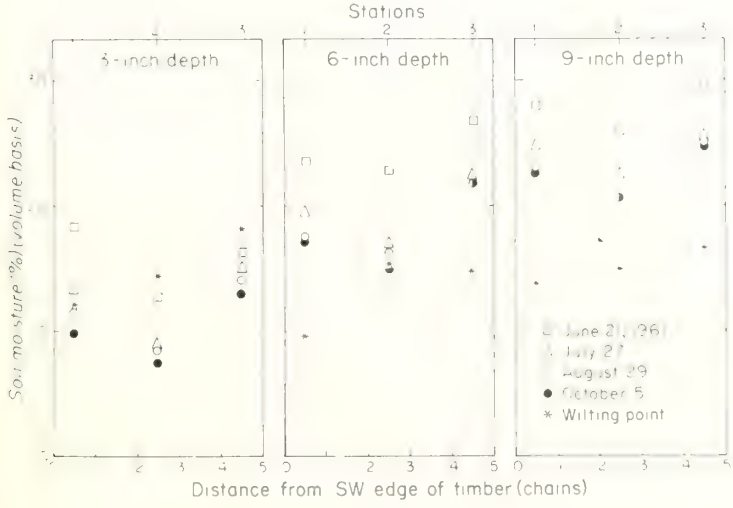

Figure 13.–*Soil moisture was measured at three depths at three points across a 5-chain wide clearcut strip. Each plotted point is an average of like points from two separate transects.*

Competitive Vegetation

In clearcut openings at Swain Mountain, the amount of low forms of potentially competitive vegetation stayed at a low level for several years. This low level undoubtedly aided initial seedling establishment, and contrasts with vegetation response at some other places.

Methods

Before timber cutting, low competing vegetation was scarce or spotty on the areas we studied. Small non-timbered openings in the Experimental Forest were occupied by several low species which could be seed sources. Viable brush seeds in the soil were expected to be at a low level in dense stands about 200 years old. We assumed that stand density would have eliminated brush at an early stage of stand development. Stand conditions at Swain Mountain appeared to differ considerably from those in which Quick (1956) found abundant viable brush seeds in duff and soil beneath old mixed conifer stands.

We had anticipated that small plants, such as forbs and grasses, might quickly become established in our clearcuttings. Each year, presence or absence of sedge, forbs, grass, brush, and ferns was recorded for all milacres of the regeneration transects. If present on a milacre, any of these classes of vegetation was rated as having an estimated light, medium, or heavy competitive effect with respect to establishment of fir seedlings. Rating was based on class, and on size, number, and distribution of plants. Fir trees of any size, on or within certain distances from a milacre, were also considered as being competitive. Trees less than 4.5 feet tall were judged like low vegetation; those taller than 4.5 feet were judged competitive if within a distance equal to 7 feet plus 1 foot for each inch of tree diameter.

Results and Discussion

Such a small amount of low vegetation developed that no effect of its competitiveness with fir seedlings could be detected in preliminary multiple regression analyses. In those analyses, all independent variables listed in the section on *Comparison of Several Major Factors* were used. Frequent observations indicated that no significant amount of vegetation was present during the summer that would not be recorded by the fall examination. Initial amounts and buildup of post-logging vegetation in any of the specific classes varied from one area to another *(fig. 14)*.

Sedges *(Carex* spp.*)* appeared during the same season as cutting, and gradually became the predominant plants on several cutting areas. In a few places, small patches of grass reached such density that they appeared to inhibit seedling establishment. Ferns were rarely found. A variety of forbs, mostly small plants, was noted. A 3- to 4-foot tall thistle *(Cirsium* sp.*)* was the only large species which became established. And it was limited primarily to one cutting area. A few specimens of gooseberry and currant *(Ribes* spp.*)* were seen. Mountain whitethorn ceanothus *(Ceanothus cordulatus* Kell.*)* was the only brush species which became noticeable. Its distribution suggests that the expectation of essentially no viable brush seed beneath dense old fir stands is untenable. Germination was heaviest where slash fires best broke seed dormancy. Deer kept this brush species cropped to insignificant plant size for about 3 years. Spine-tipped branchlets then developed, and deer found the plants less palatable.

These observations show that, even within the small area of the Experimental Forest, establishment of low vegetation after timber cutting may be quite variable from place to place.

Analysis of 1965 data for clearcut strips showed that type of slash treatment had a highly significant effect on subsequent establishment of low vegetation. Some vegetation was rated on 48 percent of bulldozer-cleared milacres, on 35 percent where there was no slash treatment, and on 27 percent of lop-and-scatter milacres. Slash treatment had no significant effect on the relative number of milacres stocked with any one of the four classes of vegetation (sedge, forbs, grass, or brush).

Obviously, competition from low forms of vegetation was insignificant at Swain Mountain. Elsewhere, competing vegetation has been a serious deterrent to fir seedling establishment, or at least to early rapid growth. In one well-documented[7] instance, some strips clearcut in 1954 had adequate seedlings established on them soon after logging. A heavy growth of *Ribes* spp. and other plants also became established, apparently later. After 10 years, fir seedlings were scarce except in a band extending about a half-chain from one cutting edge. In this extreme case, seedlings at least appear to have been eliminated by competition from other vegetation. More usually, firs will become established and grow slowly under brush, eventually overtopping and killing it. But the time used in this process generally is greater than forest managers should tolerate.

Vegetation potentially competitive with fir reproduction will vary from place to place, and should be

[7]Unpublished data on file at Pacific Southwest Forest and Range Exp. Sta., U.S. Forest Service, Redding, Calif.

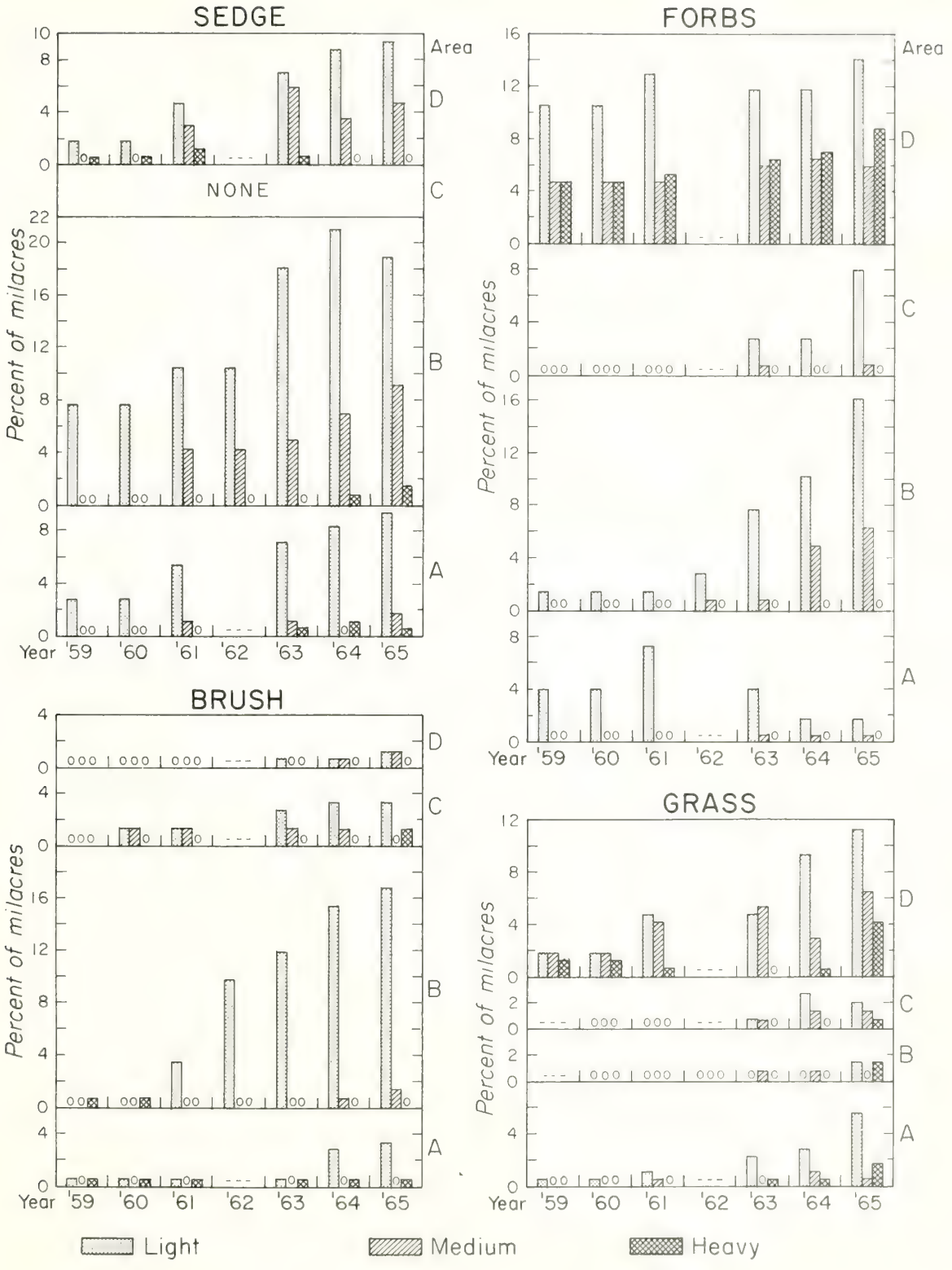

Figure 14.–*Portions of all milacres having sedge, forbs, brush, or grass rated as light, heavy, and medium competition to fir seedlings, by cutting area and year.*

evaluated wherever seedling establishment and good growth rate is desired. Appropriate treatments will have to be designed, probably locally, wherever control of undesirable vegetation is necessary.

Seedling Survival, Abundance, Distribution

Methods

New seedlings—how many are there, and where are they? Two basic sources are available for answering these inquiries: (1) data from annual fall examinations of all milacre transects, and (2) results of more detailed and frequent examinations of 22 of the milacres on those transects, plus 2 additional milacres in a narrow opening, during a 3-year period, 1963-1965. The numbers of fir seedlings initially recorded in the transect data were 1,041, and in the detailed study 341.

The lot of 24 milacres in the detailed study included a wide range of seedbed conditions and distances from cutting edges. The purpose of this study was to gain information on trends in seedling numbers during the early establishment period. In 1963, a flush of new seedlings, mostly white fir, was examined weekly. In 1964 and 1965, survivors among these same seedlings were observed at approximately monthly intervals.

In charts and tables, seedlings shown as ages 1, 2, and 3 are annual survivors of the seedling crop originating in spring 1963, only. Seedlings in the "all" age category are those originating since logging, and surviving to any age in 1965.

Results and Discussion

The number of live seedlings on the 24 milacres dropped rapidly from late June to mid-August during the first year *(fig. 15)*. By the end of September the number was comparatively stabilized. At the last examination for the year, October 28, survival was about 20 percent of the original base for seedlings on 22 milacres on 3- and 5-chain wide strips, and 46 percent on the two milacres in the narrow opening. Survival on clearcut strips at the end of the second year was 14 percent, and at the end of the third year, 11 percent. Superiority of the narrow 1-1/4-chain opening is shown by the 26 percent survival level at the end of the third year.

The other results reported in this section are based on fall examination of all milacre transects on clearcut strips.

Beginning with seedlings from the 1960 seed fall, the 3-chain wide strip continuously demonstrated superior seedling establishment to the 5-chain wide strips. The chief measurable reason was seed fall, but reasons for higher level of seed fall on the narrow strip were not obvious *(fig. 3)*. Both stocking and average number of seedlings per milacre were greater for the narrow strip than for wide strips *(fig. 16)*.

Further evidence favoring narrow strips, or small openings, is found in a comparison of seedlings established at greater or lesser distances from cutting edges. More than twice as many seedlings were present within a chain of seed source as at greater distances *(table 6)*. Number of seedlings near the northeast edge of clearcut strips was usually slightly lower than near the southwest edge. But the difference was inconsequential, so seedling and stocking data for the two edges were combined for averaging.

Evidence indicates that narrow or small clearcuttings will regenerate with more certainty than wide ones. We may infer that even with relatively light seed fall, we might get satisfactory regeneration on narrow strips, but we might not on wider areas.

Type of seedbed affected seedling abundance and distribution *(table 7)*. Except in the class of information "average seedlings per milacre for stocked milacres only," the highest seedling frequency at any age was on "mineral soil." "Light litter and slash"

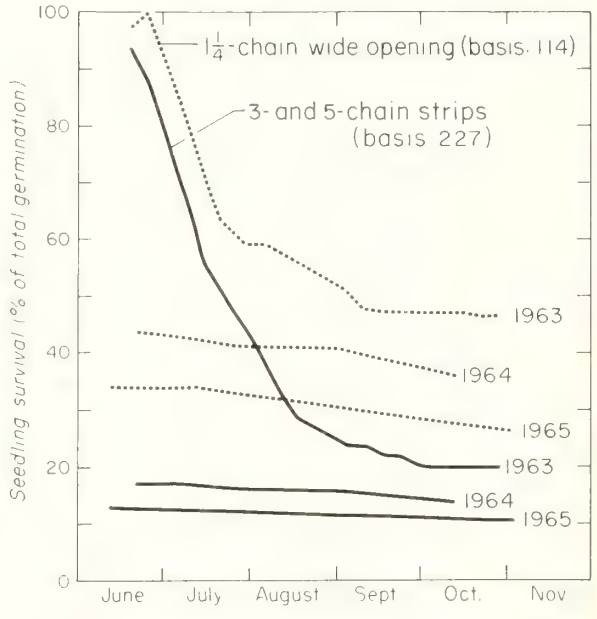

Figure 15.—*Seasonal survival trend of fir seedlings, first 3 years, in narrow and wide openings, shows a decline from the first year. Total germination is shown. Germination was not complete until July 8. That and mortality rates are responsible for curve origins and their early shape.*

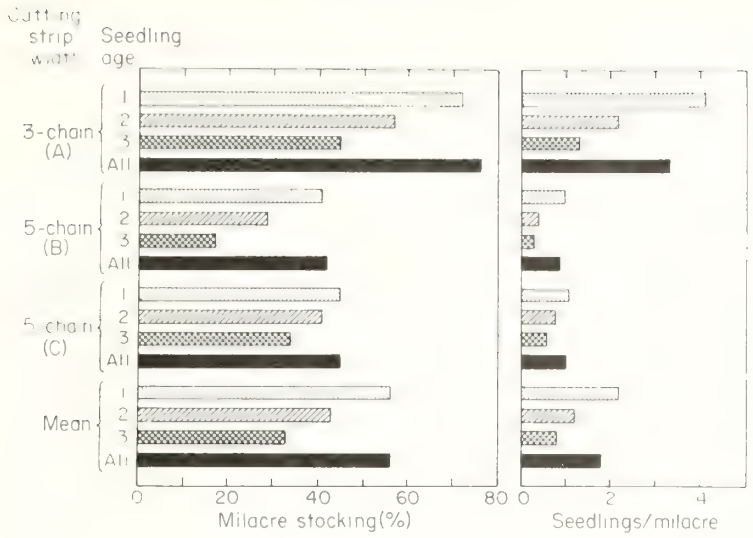

Figure 16. *Size of clearcut strip affected stocking and mean seedlings per milacre (all milacres). "All"= all post-logging fir seedlings, any age, in 1965; ages 1, 2, 3, are seedlings of 1963 origin in 1963, 1964, and 1965.*

was quite favorable through the second year, but after that, it yielded its relative position to seedbeds with medium to heavy amounts of litter or slash or both. Stated another way, after the first year, survival of seedlings was relatively better on seedbed classes with heavy litter than on those without. This phenomenon is most evident if only stocked milacres are considered. Reasons for this switch are unknown. Seedling distribution on milacres with "mineral soil" or "light litter and slash" is generally superior to that on other seedbeds.

Red fir seedlings appear to be more tenacious than white fir *(fig. 17)*. Red fir survival for an even age class was examined in 1961 and from 1963 to 1965. Similar white fir records cover 1963 to 1965. Survival at the end of the third growing season was 54 percent for red fir, 36 percent for white fir—both percents based on number of seedlings at end of the first season. By the end of the fifth season, nearly 48 percent of the red fir still survived. These records may be confounded by differences in weather or other conditions by years, but are the only early local evidence that red fir appears to be superior not only in survival but in early vigor as well. Probably most informative of all, however, are results of a cursory survey of all cutting areas made in fall of 1969. The dominant seedlings remaining are all red fir of 1961 origin. Stocking is still high. The only white fir seedlings of early origin which remain are stunted to a few inches of height by browsing. Red firs in free-growing positions now average 3.8 feet in height, and grew 0.8 foot in 1969, 0.9 foot in 1968. They appear to be thriving.

The number of seedlings surviving at the end of

Table 6.– *White and red fir seedling abundance and milacre stocking on clearcut strips at less or more than 1 chain from cutting edge*

Seedling age	Year	Distance from edge	Average seedlings per milacre, all milacres	Index of seedling abundance	Stocking[1]	Stocking index
		Chains	*Number*	*>1 ch=1*	*Percent*	*>1 ch=1*
1	1963	<1	3.2	2.7	63	1.3
		>1	1.2	1.0	49	1.0
2	1964	<1	1.7	2.4	49	1.3
		>1	.7	1.0	38	1.0
3	1965	<1	1.1	2.2	39	1.5
		>1	.5	1.0	25	1.0
All[2]	1965	<1	2.5	2.1	61	1.2
		>1	1.2	1.0	51	1.0

[1]Stocking percent = (number of milacres with one or more seedlings / total milacres in distance class) X 100.
[2]All post-logging red and white fir seedlings, any age.

Table 7.– *Seedbed-seedling relationships on clearcut strips, white and red fir seedlings combined*

Seedling age and year and seedbed class [1]	Average seedlings per milacre		Index of seedling abundance[2,3]	Stocking [4]	Stocking index[3]
	Stocked milacres only	All milacres			
	Number		*Percent*		
1 – 1963:					
1-Mineral soil	5.8	4.1	2.4	71	1.2
2-Light litter, slash	4.2	2.8	1.6	65	1.1
3-Slash	4.1	2.0	1.2	47	.8
4-Heavy litter	3.6	1.6	.9	45	.8
5-Heavy litter, slash	3.0	1.7	1.0	58	1.0
Mean	3.9	2.2	--	56	--
2 – 1965:					
1-Mineral soil	3.3	1.9	1.9	57	1.3
2-Light litter, slash	2.5	1.2	1.2	48	1.1
3-Slash	2.7	.8	.8	29	.7
4-Heavy litter	3.4	1.1	1.1	34	.8
5-Heavy litter, slash	2.4	1.0	1.0	42	1.0
Mean	2.8	1.2	--	43	--
3 – 1965:					
1-Mineral soil	2.6	1.2	1.7	45	1.3
2-Light litter, slash	2.1	.6	.9	27	.8
3-Slash	2.4	.4	.6	16	.5
4-Heavy litter	3.0	.9	1.3	30	.9
5-Heavy litter, slash	2.0	.7	1.0	34	1.0
Mean	2.4	.8	--	34	--
All[5] 1965:					
1-Mineral soil	4.0	2.9	1.9	72	1.3
2-Light litter, slash	2.2	1.4	.9	62	1.2
3-Slash	2.3	.9	.6	40	.7
4-Heavy litter	3.7	1.8	1.2	49	.9
5-Heavy litter, slash	2.8	1.5	1.0	54	1.0
Mean	3.2	1.8	--	56	--

[1]Seedbed classes as rated in specified years.
[2]Basis: all milacres.
[3]Seedbed class 5 = 1.0.
[4]Stocking percent = (Number of milacres with one or more seedlings/total milacres in class) X 100.
[5]All post-logging red and white fir seedlings, any age.

each growing season during the period of study is shown in figure 18. Data include both fir species on all milacre transects on the three clearcut strips. Omitted from the histogram are one seedling each established in years 1959 and 1960. The usual pattern of reproduction waves, reported in other investigations within the genus, is apparent in this record. Seedbed conditions on the cutting strips improved with time (see section on *Seedbed Condition*). Competitive vegetation presented no problem through 1965. It has increased each year, but new seedlings from at least two seed crops since 1965 are present on all areas. Their continued survival is, of course, uncertain.

Seedling survival on the clearcut strips, as arranged by year of origin, permits an important inference *(fig. 18).* It is that at this particular time and place we were fortunate that competitive vegetation did not become established in heavy amounts before fir seedings became established. More specifically: (a) the areas represented by data in figure 18 were logged in 1958 and 1959; (b) the first small wave of seedlings did not appear until 1961; (c) a "bumper crop" of seedlings did not get started until 1963; and (d) on these areas competitive vegetation was sparse during this time. This sequence of events contrasts strongly with events that I observed in some other fir regeneration areas, where dense vegetation became

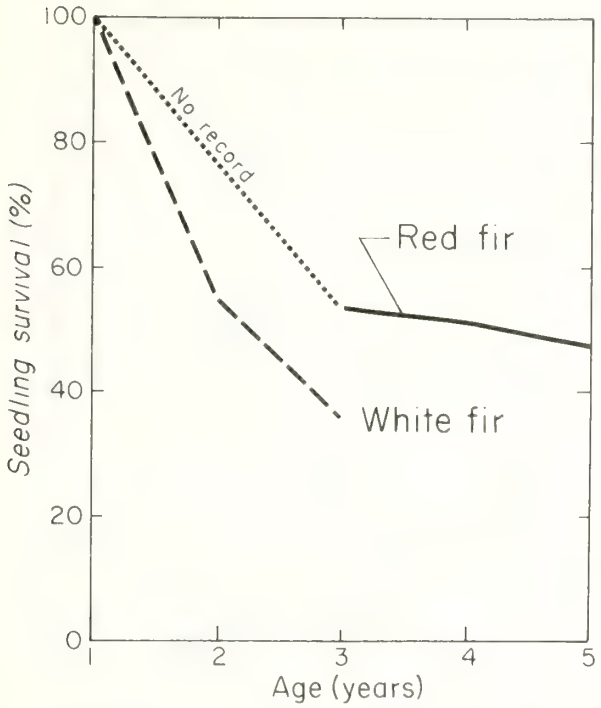

Figure 17.–*At the end of the third season, red fir had a higher rate of survival than white fir on clearcut strips. Number of seedlings for bases were: white fir, 1,030 (origin:1963); red fir: 129 (origin:1961).*

established within 2 or 3 years after logging. There, seedling establishment and early growth were inhibited or retarded.

Lodgepole pine *(Pinus contorta* Dougl.*)* was the only other species found on the milacre transects. Cones of this species are non-serotinous in the general Swain Mountain area. Isolated seedlings appeared on some cutting strips, with seed source a matter of conjecture. Only one lodgepole pine seedling was observed on transects of the three clearcut strips. The clearcut block D was next to a patch of lodgepole pine, however, and a number of pine seedlings became established upon it. Milacres with lodgepole pine seedlings were distributed evenly along 10 of the 17 chains of the transect through this cutting area. Accumulative seedling numbers on the block sample transect during the period 1958-1965 were:

Year	Lodgepole pine seedlings (number)
1961	12
1962	11
1963	120
1964	100
1965	148

This pine has faster early height growth than either red fir or white fir, and can overtop them. However, its final height is not as great. Observation of later stages of this mixture definitely indicates that the tolerant fir eventually overtops and eliminates the intolerant pine.

Seedling Mortality

Methods

In 1963, the supplemental seedling study on 24 milacres included field observations on causes of mortality for first-year seedlings. Weekly intervals for these kinds of observations were somewhat infrequent for the most precise work; nevertheless, information on factors causing most seedling losses was obtained.

Results and Discussion

At the end of the first season, seedling mortality was 71 percent. Cutworms were the most destructive agent. They killed 24 percent of the seedlings, and accounted for 33 percent of all mortality *(fig. 19).* Fowells (1940) found that cutworms killed 34.4 percent of white fir seedlings during a study on the Stanislaus National Forest. Evidence of clipping and

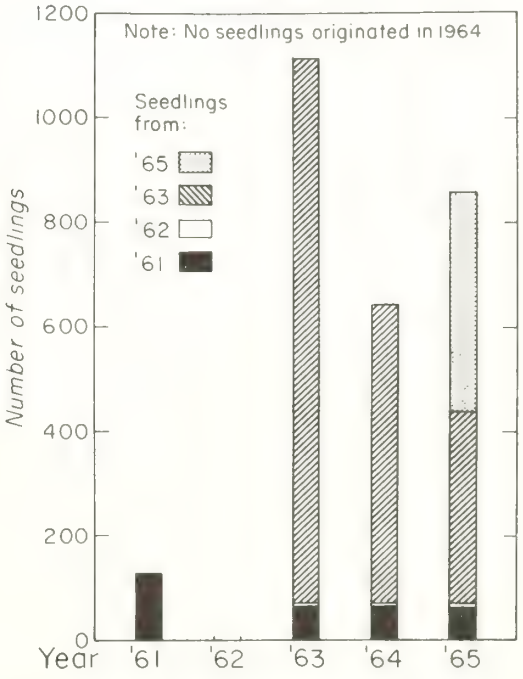

Figure 18.–*Pattern of white and red fir seedling survival followed the usual pattern of reproduction waves within the genus. Data are from milacre transects on clearcut strips. Survival was not recorded in 1962.*

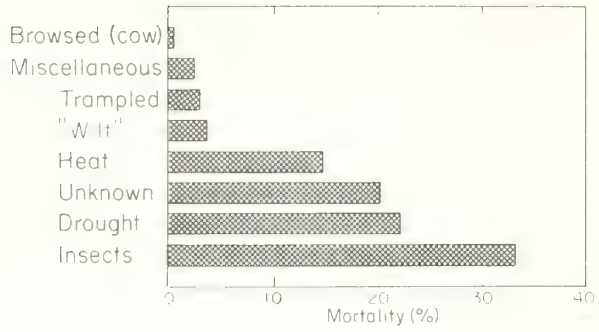

Figure 19.–*Insects and drought were responsible for more mortality in fir seedlings in the first year of growth than any other factors.*

consumption of cotyledons or stems or both at Swain Mountain was essentially the same as that observed by Fowells. Few seedlings died when less than half of the cotyledons were destroyed. Most mortality from cutworm damage occurred before July 15, but some mortality, with insect damage as the probable original cause, was recorded up to September 16.

Drought accounted for 22 percent of mortality. Many seedlings judged as drought-killed were noticed, even in early summer, to be situated in loose mineral soil or mineral-litter mixture, often associated with earth dikes resulting from tractor operation. Some of these sites appeared never to have been wet. Undoubtedly most of them had been wet–if only to a superficial degree. Otherwise the seedlings would not have survived long enough for repeated observation.

Unusual summer precipitation has an unclear effect on seedling survival. In 1963, usual dry summer conditions prevailed. On the milacre transects, 30 percent of 324 first-year seedlings (mostly white fir) survived. In 1965, unusually heavy precipitation fell in July and August. In that year, on milacre transects 107 new red fir seedlings were found initially. Only 24 percent survived at the end of the season. It seems possible to infer, tentatively, that even during normally dry summers, natural fir seedlings in openings have adequate soil moisture for survival at most microsites, and that the total of other agents will be responsible for possible high mortality rates.

Mortality attributed to heat, about 15 percent, usually was caused by excessive high soil surface temperature. Constriction of the seedling stem at ground level was used as evidence of high temperature.

Twenty percent of mortality fell in the "unknown" category, which included uncertain instances of heat or drought killing, and other kinds of seedling loss. Several staked seedlings simply disappeared, without a trace of stem left above or below ground.

"Wilt" was probably caused by damping off, but no laboratory examinations were made. Only 4 percent of mortality was from this cause, and all occurred between June 19 and July 1.

Trampling deaths were attributed chiefly to cattle, a very few to deer, and I confess to one or two. Even though trampling damage might appear slight, it was recorded when observed. Any seedling which died soon after being trampled was recorded as killed by trampling.

No deer browsing was seen in the sampled milacres, but it occurred elsewhere on the area in 1963 and at other times. Less than 1 percent of seedlings that died were pulled up by cattle.

The "miscellaneous" category contained several seedlings which were destroyed in an interesting way. They were scrubbed out by the curling action of drying limbs lying on the ground. An animal, probably a rodent, caused one death when it clipped most cotyledons from a seedling while detaching an unshed seedcoat. A little more than 2 percent of mortality was assigned to the miscellaneous category.

On June 29, 1963, a 32°F. minimum temperature at Swain Mountain killed new lateral (but not terminal) growth of white fir advance reproduction, but did not have an observable effect on recently-germinated seedlings of either white or red fir. Schubert (1956) reported for another location apparent differential response of young white and red fir to temperature below 32°F., the white fir being damaged more heavily. He also suggested that initial establishment of white fir reproduction would be better beneath the radiation and browse protection of pines or brush, the latter to be removed early to release the firs. Greater resistance to frost damage might be one reason that red fir replaces white fir as elevation increases.

About half the seedling mortality could be controlled. Cost of control measures is another matter.

COMPARISON OF SEVERAL MAJOR FACTORS

The relative influence of each of certain variables on seedling establishment at Swain Mountain is best shown through results of statistical analyses. Some of these results have been mentioned earlier. The intent here is to bring material together so that comparisons may be made.

Variables

The milacre regeneration transects and seed traps furnished data for stepwise multiple regression analyses. Only data associated with seedlings of 1963 origin were used. Data for other years were judged to have too many zero observations to allow significant or economical analysis. Variables available were:

Dependent

Seedlings per milacre (number): Total number of white and red fir seedlings on a milacre at end of the first growing season. More explicitly—we are dealing with about 20 percent of the original seedlings which survived the first growing season on 3- and 5-chain wide strips.

Seedlings per sound seed (ratio): Ratio of seedlings per milacre to estimated sound seed falling on the milacre.

Independent

Seed (number of sound seed per milacre): Number of sound white and red fir seed falling on a milacre, as estimated from seed trap data.

Distance (from nearest cutting edge seed source): Distance of milacres from seed source was used linearly, squared, or classed as greater or less than 1 chain. In some of the analyses distance was defined as being (a) from the nearest cutting edge, or (b) from the southwest cutting edge only.

Slash disposal (three methods): The three slash disposal treatments—none, lop and scatter, exposure of mineral soil by bulldozing—were coded. The intended effect of treatments was the creation of gross differences in general seedbed conditions.

Seedbed condition (five classes): Five coded classes of seedbed condition were based on mineral soil or three relative levels of litter or slash or both. A statistical test showed that the distribution of seedbed classes within 1 chain of the cutting edges did not differ from that of seedbed classes on the rest of the cutting.

Shade (four classes): Four shade classes were based on the number of small residual trees on a milacre. Size, location, or arrangement of trees on the milacre were not considered. Some milacres had more than 20 residuals. This variable was used only in analyses applying to the irregularly shaped block, since this area was entirely different from the clearcut strips.

Competitive vegetation (five classes): Each of five kinds of low vegetation which became established was rated according to its estimated competitive effect on seedling establishment in each milacre. Competition was coded as none, light, medium, or heavy. A competition index for each milacre was obtained by adding these coded numbers. Because early analyses indicated competition had no effect, this variable was dropped.

Statistical Analyses

An existing stepwise multiple regression analysis program[8] for the IBM 1620 computer was used to determine relative importance and relationship of the variables. Table 8 lists the most informative results of initial analyses. Evaluation was based on the terms expressing (a) contribution of each variable or group of variables to regression sums of squares (R^2), and (b) T-ratio (regression coefficient/standard error) for each variable, which had to be 2.00 or greater to indicate an appreciable effect.

Appropriate models were then compared by F-tests to determine (a) whether regression slopes or intercepts differed significantly, and (b) which classes of independent variables were contributing significantly to information about the dependent variables.

The most significant information from regression analyses and F-tests of the models is reported here. Major findings summarized are in terms of relative influence of each variable on white and red fir seedlings at the end of the first growing season.

Dependent Variable: Seedlings Per Milacre

1. Number of sound seed per milacre was by far the most significant variable whenever it appeared in an equation.

2. Distance from nearest cutting edge was usually significant, and had an inverse relationship to number of seedlings. Distance, as a variable, may be influenced to an unknown degree by the effects of shade from the cutting edge.

3. Differences in the influence of various seedbeds on seedling establishment were highly significant *(fig. 20).* Mineral soil (seedbed class 1) was the best

[8]Powell, Marcus P. *The new regression system.* Version 1. 1966. (Unpublished manuscript on file at Dep. Agr. Econ., Univ. of Calif., Berkeley.)

seedbed, followed by class 2, which had only light litter and light or no slash.

4. Slash treatments were highly significantly different in their influence on seedling establishment. Bulldozing to mineral soil was the superior treatment. But why lop-and-scatter treatment was superior to no treatment is not clear. Appearance of the lop-and-scatter areas for a couple of years after treatment– rather uniform distribution of a relatively deep layer of organic fines– suggests that it would be a poor seedbed initially. Apparently lop-and-scatter treatment improved with age.

5. An additional series of F tests compared regression models incorporating different combinations of independent variables within these general classes: sound seed, distance, seedbed, and slash treatment. Within and among the variables, the most significant factors contributing to high number of seedlings were, in order, (1) quantity of sound seed, (2) mineral soil seedbed, and (3) bulldozer treatment of slash (to expose mineral soil).

6. Since many milacres on the clearcut block were stocked with stems of advance reproduction, the possible influences of natural shade and seedbed on seedling establishment were examined. In this analysis, a series of linear regressions were run in addition to the multiple regressions. Results were too unreliable for inclusion here. A reliable example of the influence of small tree shade on seedling survival appears in the section on insolation under *Sunlight and Shade Influence on Seedling Survival.*

Dependent Variable: Seedlings Per Seed

During the early part of the analysis, an attempt was made to develop simple indexes of "seed efficiency" for various conditions, but no reliable information on the subject could be developed.

Table 8.– *Selected data from multiple linear regression analysis showing relative importance of variables in different combinations; applicable to clearcut strips only*

Model number	Dependent variable	Independent variables and combinations	R^2	T-ratio	Number of observations
1 a	Seedlings/milacre	Seed/milacre	0.15301	8.23	377
b	Seedlings/milacre	Distance	.05413	4.63	377
c	Seedlings/milacre	Distance	.05414	1.31	377
		+(distance)[1]		.05	
d	Seedlings/milacre	Seed/milacre	.16040	6.88	377
		+ distance		1.81	
e	Seedlings/milacre	Seed/milacre	.16054	6.87	377
		+ distance		.82	
		+(distance)[1]		.25	
2A a	Seedlings/milacre	Seed/milacre (in seedbed 1)[2]	.34536	4.76	45
b	Seedlings/milacre	Seed/milacre (in seedbed 2)	.46730	6.00	43
c	Seedlings/milacre	Seed/milacre (in seedbed 3)	.18227	3.24	49
d	Seedlings/milacre	Seed/milacre (in seedbed 4)	.05012	2.24	97
e	Seedlings/milacre	Seed/milacre (in seedbed 5)	.10801	4.13	143
2B a	Seedlings/milacre	Seed/milacre	.18021	8.55	377
		+ seedbed 1		2.74	
		+ seedbed 2		2.43	
		+ seedbed 3		.21	
		+ seedbed 4		1.89	
		+ seedbed 5		(3)	
b	Seedlings/seed	Distance	.06110	2.00	377
		+ (distance)[1]		2.29	
		+ seedbed 1		3.68	
		+ seedbed 2		2.14	
		+ seedbed 3		.73	
		+ seedbed 4		1.83	
		+ seedbed 5		(3)	
3A a	Seedlings/milacre	Seed/milacre (in slash 0)[2]	.31746	7.65	128
b	Seedlings/milacre	Seed/milacre (in slash 1)	.05882	2.83	130
c	Seedlings/milacre	Seed/milacre (in slash 2)	.14358	4.43	119

See end of table for footnotes.

Table 8.--*Selected data from multiple linear regression analysis showing relative importance of variables in different combinations, applicable to clearcut strips only*, continued

Model number	Dependent variable	Independent variables and combinations	R^2	T-ratio	Number of observations
3B	Seedlings/milacre	Seed/milacre	.16618	8.36	377
		+ slash 0		2.35	
		+ slash 1		1.75	
		+ slash 2		(3)	
4A	Seedlings/milacre	Seed/milacre	.18802	8.52	377
		+ slash 0		1.69	
		+ slash 1		.25	
		+ slash 2		(3)	
		+ seedbed 1		2.40	
		+ seedbed 2		2.31	
		+ seedbed 3		.18	
		+ seedbed 4		1.54	
		+ seedbed 5		(3)	
4B	Seedlings/seed	Distance	.07838	1.59	377
		+ (distance)[1]		1.76	
		+ slash 0		2.62	
		+ slash 1		1.38	
		+ slash 2		(3)	
		+ seedbed 1		2.80	
		+ seedbed 2		1.67	
		+ seedbed 3		1.31	
		+ seedbed 4		.95	
		+ seedbed 5		(3)	

[1](distance) squared.

[2]Legend for variables:

Seedbed

Code	Litter	Slash	
1	O	O	
2	L	O, L	
3	O	L, M, H	
4	M, H	O	
5	L, M, H	L, M, H	(except combination of L litter and L slash)

Slash

Code	Treatment
0	None
1	Lop and scatter
2	Cleared w/dozer

[3]In these instances, seedbed class 5 and slash class 2 were entered in equations with values set at 0, so no T-ratios were developed.

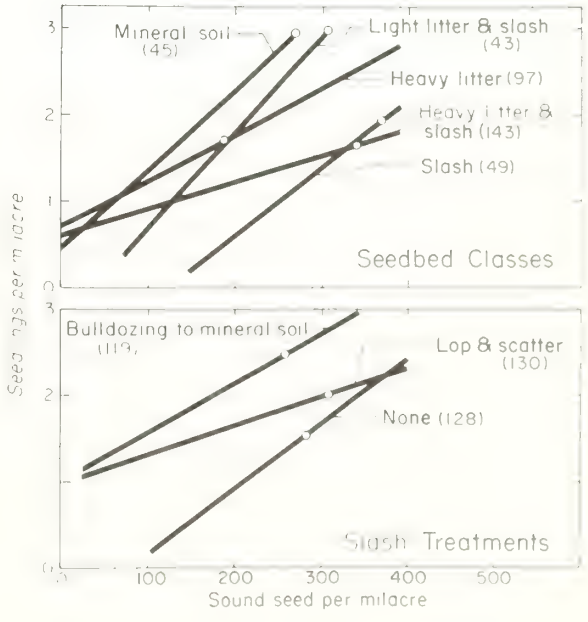

Figure 20.--*Regression lines from relating seedlings per milacre to sound seed per milacre on clearcut strips. Separate regression analyses were made for each seedbed and slash class. The number of observations is given in parentheses; means are indicated by (•).*

OTHER FACTORS IN REGENERATION

In addition to the major factors that affect regeneration of white and red firs, we studied other factors. These observations and findings were not subject to statistical analyses.

Injury and Rot

Mechanical damage to residual trees should be kept at a low level in fir stands. Fungi can become established quickly wherever fir bark is broken and may cause future losses from rot and windbreak. Such losses should not be ignored. Broken tops will reduce seed production potential for a number of years, since all fir cones are produced close to tree tops. To help keep injuries down, stands may be logged in two or more stages. Experience has shown stage-logging to be essential to minimize log breakage where timber stand volumes are heavy.

Wind Damage

Wherever fir stands are opened, increased wind damage may occur. The amount of wind damage seems to be related to amount of timber removed from an area. Size and shape of openings, orientation, topographic location, and direction of prevailing storm winds should be considered. Individual tree or small group cuttings may help to reduce wind damage. Intensity of cutting, and spacing of residual timber, is the key. Heavy wind damage after heavy cutting is common. But I do not know of any recorded information on wind damage to white or red fir residuals in "medium" or "light" selection cutting, although I have seen such damage. Harvesting plans should provide for salvaging wind damaged trees.

Dwarf Mistletoe

Dwarf mistletoe is present in varying amounts in many fir stands. Two simple methods can reduce its spread to new seedlings or advance reproduction. The first is to remove nearby infected trees soon after adequate regeneration has been established—certainly before seedlings are 3 feet high. Scharpf (1969) has shown that if an overstory is infected, understory trees have low, medium, or high amounts of mistletoe in the same direct relationship to their height. The second method, which may have less frequent application, relies on artificial seeding or planting. Since the two forms of dwarf mistletoe growing on white and red fir are host-specific (Parmeter and Scharpf 1963), regeneration of one species can be established beneath or next to mistletoe-infected trees of the other without danger of infection of the seedlings.

Animal Damage

In localized situations, birds, cattle, and other animals may be important enough to require special attention. At present, insects, deer, and rodents hold the highest potential for causing difficulties in fir regeneration. Specific instances of damage are numerous, and, even after years of study, there is no reliable method of controlling these animals in an acceptable way and at reasonable cost.

Insects

Although cone- and seed-eating insects often greatly reduce seed supplies, I know of no research having been done to guide alleviation of this problem in fir species. Insecticides can probably control cutworms in the soil, but a high level of control of seed-destroying insects through use of insecticides or by other means would be much more rewarding in a number of ways, including more seed and fewer seed trees necessary.

Rodents

McKeever's studies (1961; 1964) indicated that (a) gross rodent populations in a true fir forest are lower than in nearby ponderosa and lodgepole pine forests; (b) the pine squirrel *(Tamiasciurus douglasi)* moves to areas where food is most abundant; (c) the golden-mantled ground squirrel *(Citellus lateralis)* sometimes moves from one forest type to another, and is more abundant in cutover than in uncut stands; and (d) deer mice *(Peromyscus maniculatus)* and chipmunks *(Eutamias* spp.*)* are generally most numerous of the rodents found in forested areas of northeastern California. Tevis (1956) found that the golden-mantled ground squirrel moved into Douglas-fir and white fir forests as they were progressively opened by logging. That more rodents will move into true fir forests as they are progressively logged seems probable. This could cause difficulty with true fir regeneration. During several years following first cutting at Swain Mountain, rodents did not seriously interfere with the regeneration process. However, potential rodent activity at any specific area should be evaluated for its impact on regeneration processes.

Porcupines seem to cause little damage in fir forests. Pocket gophers, however, are sometimes

active in wet meadows and occasional open glades, so their numbers and activities may need evaluation.

Deer

Deer browse heavily upon small firs in some areas. The most succulent new growth of the current or immediately preceding year always is browsed in preference to older tissue. Browsing may eliminate plants or greatly restrict their height growth. In some locations, small firs may be the only green food available as deer follow the spring snow melt to increasingly higher elevations. Regeneration of firs or any other species may be difficult along the main annual migration routes of large deer herds.

Logging Plans

In planning roads, skid trails, and fire lanes, and in marking timber, the future as well as the present should be considered. Otherwise, current activities may obstruct or make less efficient future harvesting or cultural work. Future activities could also destroy recently acquired regeneration if improper logging activities are forced or permitted.

TENTATIVE RECOMMENDATIONS

General

Where natural regeneration of white or red fir is sought, creating conditions which have high probability of insuring at least minimum stocking from light seed fall can be recommended. This is most advantageous when factors (e.g., vegetation, erosion) related to time after logging might critically inhibit seedling establishment.

Can too many fir seedlings become established? I do not believe so. Studies to date on free-growing fir seedlings and saplings (free of overstory) indicate that several thousand young trees per acre will grow rapidly and become thinned gradually through competition and snow damage. And gains from Christmas tree harvesting can add income above "making thinning pay for itself." Nevertheless, research is needed to compare growth and other data in thinned and unthinned stands of "unmerchantable" size.

The following recommendations offer a framework for securing natural white or red fir seedlings where desired. Timber cutting techniques or patterns, and simple cultural work, are tools for accomplishing this objective. These recommendations are based mainly on two premises: (1) sound seed supply must be abundant, and (2) a treated seedbed, preferably mineral soil, will ensure advantages not otherwise gained. Emphasis is placed on cutting method.

Clearcutting

Clearcutting is the most practical method of harvesting true firs where stands of old-growth timber are dense (no understory) or light with abundant understory. The latter instance can be labeled "release" or "liberation," and little or no new regeneration is sought. Reasons for clearcutting are based mainly on logging simplicity, the confinement of potential damage to residual trees along cutting edges, ease of cultural treatments such as preparation of seedbed, ease of fire hazard reduction, and probable benefits in managing even-aged stands. Other cutting methods will be found preferable in many instances, but wherever possible, clearcutting probably will be used. Dimensions of clearcut units are of fundamental importance where new regeneration is sought.

- *Dense Old-Growth, No Understory: Clearcut Strips*

Limit width of strips to 2 or 3 chains where a solid wall of seed trees exists on both sides. Use narrower strips where seed trees are less abundant. Straight sides are not essential to regeneration. Orient generally with consideration for slope, topographic position, prevailing wind pattern, and insolation. Cut progressively toward wind or sun later. Strips can be cut sequentially to make use of Anderson's (1956) "wall-and-step" method of maximizing snow accumulation and delaying melt, particularly in cases where long cutting cycles can be used, and where mistletoe infection has low potential or can be tolerated.

- *Dense Old-Growth, No Understory: Clearcut Blocks*

Keep blocks small, not more than 3 or 4 chains in greater dimension. (The influence of seed fall from all surrounding timber probably will allow greater dimensional limits here than with strips.) As with strips, keep dimensions smaller where seed trees are less abundant. When planning the first cut, determine how succeeding cuts will be made.

- *Scattered Old-Growth, Abundant Understory*

Cutting stands like this often consists only of removing the overstory with enough care to minimize

damage to the advance growth. Experience indicates that damage to the advance growth increases with density of overstory and as size of the understory increases. Leave a good seed source at any localized spot where logging damage may become unusually severe.

Other Cutting Methods

A wide variety of partial cutting methods and intensities probably will secure adequate regeneration. We know that new fir seedlings will become established in moderate-sized openings, and in rather dense shade. If shade is dense, seedling growth will be slow until competing vegetation, whether trees or brush, is removed. No partial cuttings were studied at Swain Mountain, but available evidence—including work reported in this paper, observable patterns in the woods, and survey of the literature as far back as Dunning's (1923) early work—indicate that true firs will regenerate in partial cuttings. Limitations of cutting intensity, however, still need investigating. In one case, we found that a cutting which left about 10 large seed trees per acre adequately restocked an area. But in another similar cutting, the area was not restocked. Reasons for the difference are unknown.

- *Uniform Shelterwood System*

Areas of dense old-growth having little or no understory can be harvested to leave a fairly uniform distribution of large seed trees which should be harvested in one or more increments as regeneration becomes established. Probably more than 10 seed trees per acre should be left—at least until we gain more experience with intensity of cut.

- *Group Shelterwood System*

Areas of dense old-growth having little or no understory can be harvested in small groups to begin a cycle like that described in the next section. Groups or areas of advance growth which have no overstory could be used as focal points around which new regeneration is sought by cutting old-growth on the perimeter. Although entire perimeters might be cut, preference should be given to cutting towards the south or the prevailing wind—provided that seed trees exist in such directions. Early trials should be conservative, extending about 1 or 1½ chains into the old-growth. (In the initial stage or stages, this cutting might approach the "honey-comb" system recommended by Church [1933] for inducing greater deposition of snow and delaying its melt.)

- *Selection System*

Where stands with pronounced crown differentiation occur, remove individual trees or small groups from the upper canopy so residual seed trees will remain within 1 or 2 chains of the cutting—preferably "upwind" from the cutting.

Also, selection cuttings could be made in dense old-growth of relatively uniform height. Either slow or rapid conversion of stand appearance and other characteristics could be achieved this way.

Reproduction which becomes established in the very small openings created by selection cutting will grow slowly until released, or until it grows into the large pole class. This pattern occurs frequently in natural stands.

SUMMARY

Several factors that influenced the establishment of white and red fir seedlings from natural seed fall were studied at Swain Mountain Experimental Forest, in northeastern California, beginning in 1958.

The choice of even-aged management for early studies at Swain Mountain necessarily has influenced the nature of the work reported. Liberation cutting, and clearcutting for natural regeneration of white and red fir were the only cutting methods used to any extent in the first trials. The regeneration cuttings were confined to 3-chain and 5-chain wide strips and a single 8-acre block. Liberation cuttings were applied to irregularly-shaped areas to almost 40 acres in size. We anticipated that some small areas within the liberation cuttings might require regenerating. Accordingly, data were obtained from three clearcut strips and a block, and from one liberation cutting—or from uncut areas immediately next to them.

Cone crops of both white and red fir were found to be irregular in size and occurrence. Tree-for-tree, white firs produced much more sound seed than red firs. Individual white fir trees tended consistently to produce seed either at a relatively high or low quantitative level whenever there was a crop; individual red firs produced cones at irregular levels.

Sound seed fall on a particular location varied quantitatively with (a) relative size of seed crop, (b) abundance of seed trees, (c) distance and direction from seed trees, (d) and direction of wind currents. Wind speed was not measured, but is a significant

factor in seed distribution. Weather conditions in the fall season can strongly affect the timing of cone-shattering, and consequently the eventual effectiveness of released seed. Seeds falling on the ground before permanent snowpack may germinate in spring and survive. But most seeds falling on snowpack germinate within the pack and die when snow-melt lays the seedlings on the ground.

Mineral soil and soil with less than one-fourth inch of litter proved to be better seedbeds than heavy accumulations of litter and slash. Soil surface temperature may account for much of this difference. In one experiment, the surface of mineral soil seldom exceeded 150°F., while inch-deep litter usually exceeded 163°F.

Early survival of seedlings was better where they were shaded by small trees, artificial objects, and uncut timber edges than where they were unshaded.

Soil moisture at the 6-inch depth and deeper across a 5-chain clearcut strip remained above the assumed wilting point throughout the growing season. At the end of the first growing season numerous seedlings are known to have roots from 6 to 12 inches long. Therefore, drought was not an overwhelming obstacle to seedling establishment, although 20 percent of the seedling mortality was attributed to drought caused by microsite conditions.

Low vegetation which could compete with fir seedlings remained scanty for several years after clearcutting. This phenomenon and the timing of seed crops probably account for the generally good stocking of fir seedlings at most locations within clearcut strips at Swain Mountain. At the end of 7 years, milacres in the central portions of clearcut strips were about 50 percent stocked with post-logging seedlings. Stocking within a chain of cutting edges was higher.

More seedlings survived in narrow than in wide openings. Red fir seedlings were definitely more tenacious and vigorous than white fir in the strips studied.

Cutworms, drought, and heat at soil surface were the principal early causes of seedling mortality. About half that mortality could be controlled by some means. A few years later, deer browsing preferentially on white fir caused much mortality and delayed height growth.

Analyses of data from Swain Mountain indicated that the most significant factors favoring establishment of white and red fir seedlings are in order of importance: (a) quantity of sound seed, (b) mineral soil seedbed, and (c) some amount of shade. On the negative side, we found that destruction of seeds and seedlings by insects caused by far the greatest reduction in regeneration potential, and that deer browsing creates havoc, especially with white fir seedlings. Excessive insolation and drought were the next most damaging agents to seedlings. Other factors were relatively insignificant.

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SEED VIABILITY, GERMINATION AND RADICLE GROWTH OF DWARF MISTLETOE IN CALIFORNIA

Robert F. Scharpf

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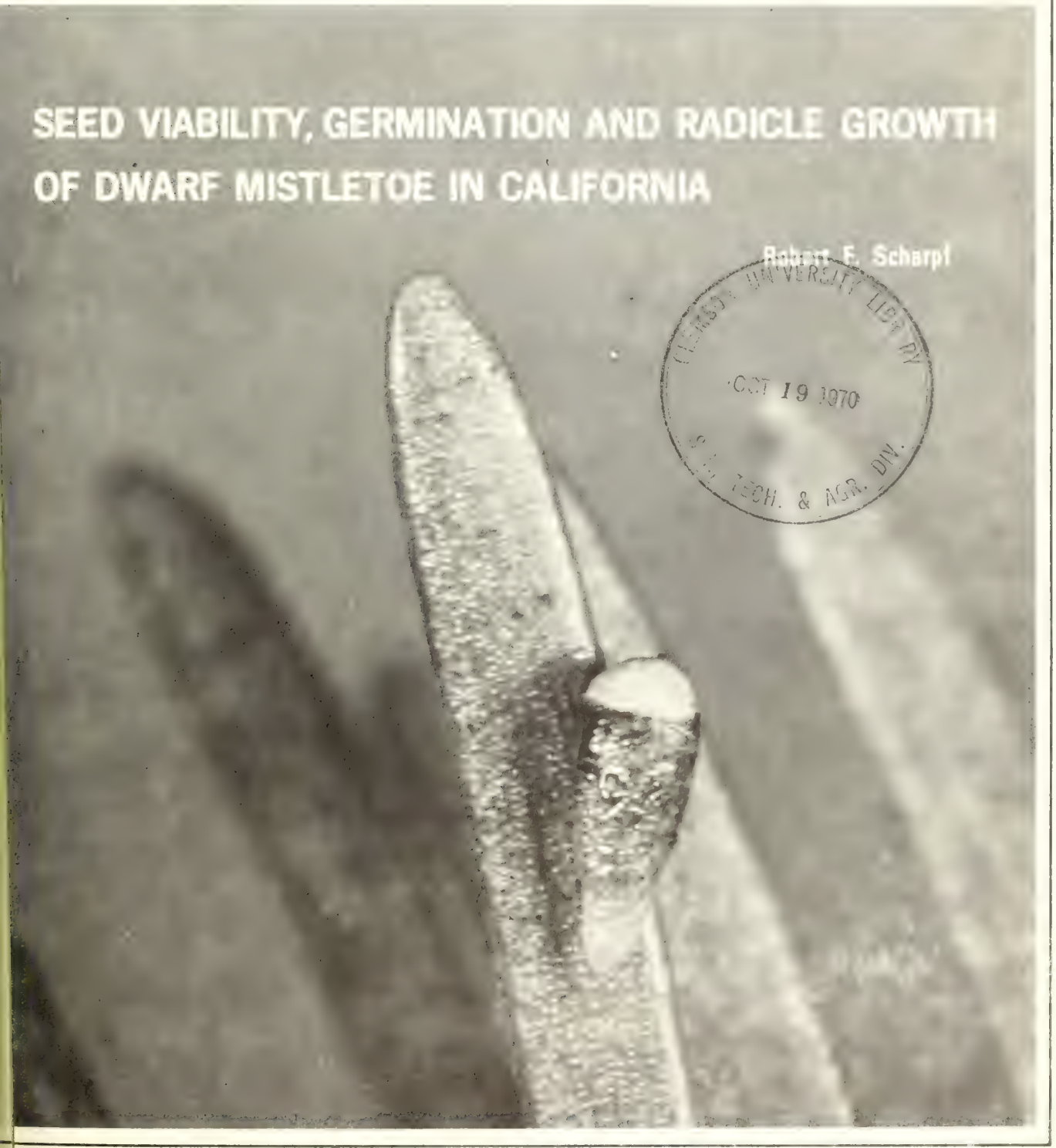

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The Author

ROBERT F. SCHARPF, a plant pathologist, is studying problems in forest diseases and their control. Native of St. Louis, Mo., he earned a forestry degree (1954) at the University of Missouri. He also holds a master's degree in forestry (1957) and a doctorate in plant pathology (1963) from the University of California, Berkeley. He joined the Forest Service in 1960, and has been with the Station's Berkeley research staff since then.

Influences on viability and germination of seeds have been studied intensively for many years, particularly for the numerous commercially important agricultural, ornamental, and timber species. Consequently, a voluminous literature exists on the physiology of seeds (Barton 1967).

Some attention has also been given to the physiology of seeds of the mistletoes, family Loranthaceae, because the mistletoes are damaging parasites of other plants and also because they have certain unusual seed features. Among these features are: (a) the seeds of mistletoes must germinate, grow, and establish a parasitic relationship with a host plant or they will die; and (b) the seeds of mistletoes are not exposed to a subterranean or soil surface environment, but on the contrary, are found on the surface of branches or twigs above the ground and therefore are exposed to climatic or environmental conditions that differ from those of seeds in the soil.

The seeds of dwarf mistletoes, genus *Arceuthobium* in particular, are quite different in several ways from seeds of most plants. For one, the seed is borne in an elastic fruit, usually one per fruit, that when ripe bursts and shoots it for a considerable distance like a miniature rifle projectile. This means of dispersal is accomplished by the buildup of internal water pressure.

The seeds do not have a seed coat, but are surrounded by an endocarp to which are attached long filamentous cells, commonly called "viscin cells." These cells rupture at seed discharge, and release a sticky mucilage which enables the seeds to stick to objects they strike. The mucilage, when wet by rains, becomes slippery however, and enables the seed to slide along a needle to a branch or move firmly into position on a branch where germination and penetration can occur. With prolonged rain the viscin washes from the seed. The viscin cells firmly attach the seed to the host upon drying. These dried cells also function as a seed coat by providing a protective shell around the endosperm and embryo, thus reducing water loss.

The presence of chlorophyll in the endosperm is another unusual feature of dwarf mistletoe seeds. Except in some mistletoes, chlorophyll does not occur in the endosperm of flowering plants (Kuijt 1960). It is possible that photosynthesis does take place in the seed and supplies the embryo with food and energy necessary for germination and infection of the host.

Some studies have been made of the physiology of seed of dwarf mistletoes, but much information is lacking. Therefore, because dwarf mistletoes are extremely damaging parasites of conifers in the Western United States, any information that may aid in their control is useful.

This paper reports results of studies undertaken to discover more about the influences on seed viability, germination, and radicle growth of two species of dwarf mistletoe: *A. abietinum* (Engelm.) Hawksworth and Wiens and *A. occidentale* Engelm.[1] so that better understanding might lead to better control.[2] These two species were selected for study because I believe they represent dwarf mistletoes that grow under markedly different environmental regimes in the Western United States. *A. abietinum* grows on red fir *(Abies magnifica* A. Murr.*)* and white fir *(A. concolor*[Gord. and Glend.] Lindl.*)* in the higher elevations of the Sierra Nevada; whereas *A. occidentale* commonly occurs on pines *(Pinus sabiniana* Dougl. and *P. radiata* D. Don*)* in the foothills of the Sierra Nevada, in the coastal mountains, and at near sea level along the California coast.

---

[1]Recent studies by Frank G. Hawksworth at the Rocky Mountain Forest and Range Experiment Station,Fort Collins, Colorado and Delbert Wiens, Department of Biology, University of Utah, Salt Lake City, Utah have shown that *A. abietinum* (previously *A. campylopodum* f. *abietinum*) and *A. occidentale* (previously *A. campylopodum* f. *campylopodum*) are no longer forms of *A. campylopodum* but distinct species.

[2]The information reported is based on a dissertation submitted to the Graduate School, University of California, Berkeley, in partial fulfillment of the requirement for the Ph.D. degree.

VIABILITY

The term "viability" has been variouly used for seeds and has led to confusion. To some writers, viable seeds are those that have the capacity to germinate. To others, any living seeds are viable. Chemical tests have also been used to determine viability. These tests detect chemical reactions that usually but not always occur in living systems. Therefore, in my review of the literature on seed physiology, it must be kept in mind that viability is not a precise term.

For the most part the environmental conditions that influence viability are not well understood. Weir (1918) suggested that *Arceuthobium* sp. seeds stored over the winter under cool, moist conditions could be used for inoculation in the spring under warm, dry conditions. However, seeds lost viability rapidly, presumably as a result of evaporation of moisture from the endosperm. Gill (1954) and Hawksworth (1961), studying *A. vaginatum* (Willd.) Presl, reported that seeds which remained dormant on hosts for a period of 2 months failed to germinate. Scharpf and Parmeter (1962) found that dry stored seed of *A. occidentale* retained viability longer at near-freezing temperatures (2°C.) than at temperatures much above or below freezing. Wicker (1967) also noted a high percent viability of seeds of three species and four subspecies of dwarf mistletoe stored dry at 5°C. for 60 days. Seeds stratified in sand or stored under moist cold conditions lost viability rapidly because of deterioration by mold fungi. According to Beckman and Roth (1968), viability of dry stored seeds of *A. campylopodum* f. *campylopodum* was highest at 1.5°C. and decreased as temperature increased.

Heinricher (1915) suggested that light prolonged the viability of seeds of *A. oxycedri* (DC.) M. Bieb. He reported that seeds kept in the dark suffered "injury and destruction" of the embryo. After 3 months' storage in the dark only 7 percent of the seeds germinated when transferred to moist filter paper.

Because information is lacking on influences on seed viability, several studies were undertaken. These include (a) the variation in viability of freshly collected seed from different dwarf mistletoe plants in different years and from different areas; and (b) specific influences such as temperature, light, moisture content of seeds, and relative humidity.

Determination of Viability

Before any intelligible discussion can take place, a definition of viability is needed. As mentioned previously, viability often means the ability of seeds to germinate. However, preliminary studies showed that dwarf mistletoe seeds are not only slow to germinate but require some rather specific conditions for germination. Therefore, a commonly used chemical test was used as the standard method to determine viability in the present study (Flemion and Poole 1948). The test is commonly called the "tetrazolium or TTC test." Scharpf and Parmeter (1962) summarized the use of this method on seeds of *A. occidentale*.

As applied in the present study, the method is essentially as follows: dwarf mistletoe seeds were first placed in water until the viscin layer became swollen. They were then placed in rows on a circular piece of filter paper 9 cm. in diameter and allowed to dry; the dried viscin layer held the seeds on the paper. Each seed was then cut in half longitudinally with a sharp razor blade. The filter paper bearing the cut seeds was then placed in a 100-mm. petri dish, covered with a 0.1 percent solution of 2,3,5-triphenyltetrazolium chloride (TTC) at pH 7-8, and kept dark for 12 to 24 hours. The cut seeds were then examined for staining. Viable seeds changed the colorless TTC into an insoluble, red pigment which was observed in the embryo and endosperm. Nonviable seeds remained unstained. Seeds showing any stain were considered viable.

The accuracy of the TTC test with dwarf mistletoe seeds was initially not known. But because it had been used successfully as a test for viability with numerous other species, I assumed it would give a quick estimate of the viability of seeds of dwarf mistletoes. Later in the study, after the conditions for germination had been worked out, viability as indicated by the TTC test was compared to actual germination at what were considered near-optimum conditions. The conditions most nearly optimum for germination are summarized elsewhere in this paper. In general, they are as follows: aseptic germination of seeds on sterile distilled water at 13°C. and 500 foot-candles of light from cool-white fluorescent bulbs. Under these conditions, the viability of seed of *A. abietinum* by both a germination and a TTC test was compared *(table 1)*.

As was expected, viability decreased with length of time in storage. This was shown by both the TTC and the germination tests.

Viability, as indicated by TTC, ranged from 8 to 15 percent higher than actual germination of the seeds under near-optimum conditions. The differ-

Table 1. *Viability of stored dwarf mistletoe seeds as determined by TTC and germination tests*

Days Storage at 2°C.	TTC test		Germination test	
	Seeds	Viability	Seeds	Viability
	Number	*Percent*	*Number*	*Percent*
5	100	96	100	85
60	100	89	779	74
180	100	56	334	48

ences, however, were not statistically significant.[3] The TTC test therefore proved to be a rapid, useful technique for determining the approximate percentage of viable seeds. Consequently, all determinations of viability reported in this section are considered valid.

Variation

Knowledge of the difference in viability among seed lots is necessary; in comparative studies of viability, tests must be standardized. Therefore, the differences in viability of dwarf mistletoe seeds collected from different areas, in different years, and from different plants were investigated.

Area of Seed Collection

Seeds of *A. abietinum* were collected in 1958 from three widely spaced points in California. Viability tests were made using 200 seeds per test selected at random from seeds from several dwarf mistletoe plants. Results were as follows:

	Viability of fresh seeds (percent)
Collection point:	
Pinecrest, Tuolumne County	97.0
Bucks Lake, Plumas County	97.5
Latour State Forest, Shasta County	97.5

Differences in viability due to area of collection were not found.

Year of Seed Collection

Variation in viability of fresh seeds collected over a period of 4 successive years was also tested, using 200 seeds per year of *A. abietinum* and 100 seeds per year of *A. occidentale*.

	Percent viability			
	1958	1959	1960	1961
Species:				
A. abietinum	97.0	97.5	97.5	97.5
A. occidentale	98	98	98	98

Any differences in viability between the two species of the parasite or among the tests over the years 1958 through 1961 were too small to be detectable.

Individual Plant Source

Differences in viability of seeds collected in 1960 from individual dwarf mistletoe plants were also tested. Each treatment group included 100 seeds from four plants. Results are shown below:

	Days in 2° C. Storage	Range in percent viability
Species:		
A. abietinum	37	86-90
A. abietinum	29	85-89
A. occidentale	1	96-98

The variation in viability was not significantly different for lots of seeds from the same plants or among several plants of the same species.

In general, therefore, I concluded that viability of freshly collected seeds of dwarf mistletoe was consistently high and not significantly influenced by year of collection, area of collection, or individual plant source.

Influences on Viability in Stored Seeds

Temperature

Temperature is known to be a marked environmental influence on viability of seeds of many plants. Therefore, the effect of constant temperature on the viability of dwarf mistletoe seeds was studied. Freshly collected, air-dry seeds were placed in petri dishes and stored in the dark at temperatures of -15°C., 2°C., 13°C., and 25°C. At periodic intervals 100 seeds from each temperature group were removed and tested for viability with TTC.

The temperature at which the seeds were stored had a marked influence on viability of both species *(figs. 1,2)*. The effect of time on viability was significantly nonlinear at any one temperature. For both species of dwarf mistletoe tested, seeds retained viability longest at 2°C., while 13°C. was significantly less favorable for survival of stored seeds. Viability declined rapidly in storage at -15°C. and at 25°C.; these were the least favorable temperatures for survival. The two species did not differ significantly in their response to constant temperatures, except at

[3]The statistical significance of the data reported in this paper is based on chi-square tests or F tests. The 5-percent level of significance is used throughout.

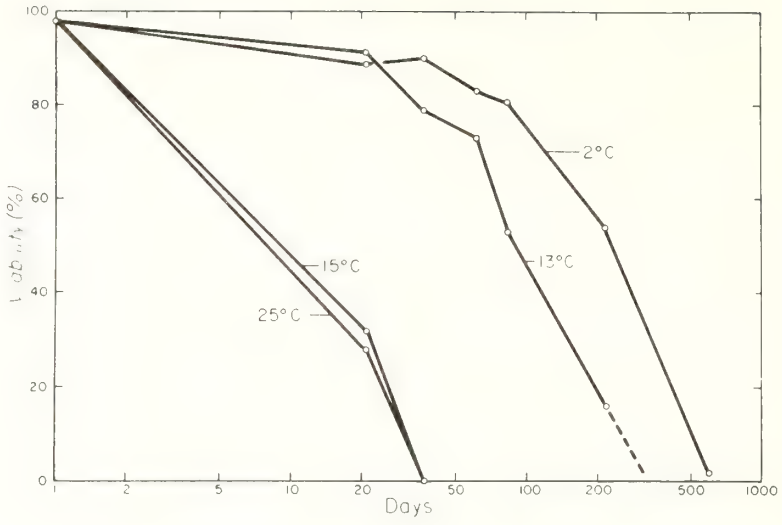

Figure 1.–*Both time and temperature affected viability of stored seeds of A. abietinum.*

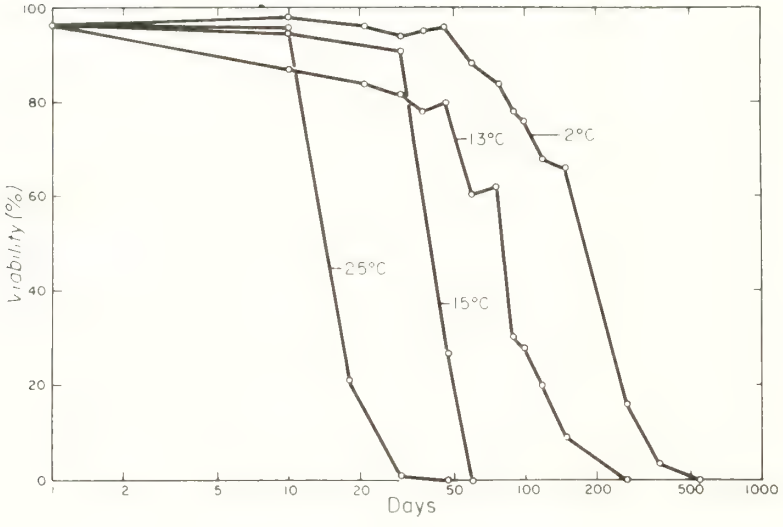

Figure 2.–*Both time and temperature affected the viability of stored seeds of A. occidentale.*

-15°C. At this temperature *A. occidentale* lost viability less rapidly than *A. abietinum.*

Light

Nothing is known about the effect of light on viability of seeds of dwarf mistletoe species of North America. Therefore, experiments were made to determine the influence of darkness, natural sunlight, and artificial light on viability of *A. abietinum* and *A. occidentale.*

Seeds were moistened and placed on circular pieces of filter paper, as described for the TTC test. Several pieces of the paper bearing seeds of each species were then placed in open petri dishes–one piece of paper per dish–and exposed to the desired light and temperature conditions. Other pieces of filter paper with the seeds were wrapped in aluminum foil to exclude light.

The following temperature and light conditions were used:

1. Natural sunlight in a greenhouse at 16°C.
2. Darkness in a greenhouse at 16°C.
3. Artificial light (500 foot-candles from cool white fluorescent bulbs) in a growth chamber at 13°C.
4. Darkness in a growth chamber at 13°C.

At periodic intervals 100 seeds of each test group were removed and tested with TTC for viability. Results of the tests on seeds of *A. occidentale* held in the dark and under natural sunlight were:

	Percent viability	
	Light	Dark
Days storage at 16°C.:		
0	98	98
15	81	86
44	62	73
63	47	58
79	34	44

Significantly lower viability was found in seeds held under conditions of natural sunlight than those in the dark. But no significant difference in viability was found between seed in continuous artificial light and in the dark for either species of dwarf mistletoe *(table 2)*. In all tests the decrease in viability was essentially linear with respect to time.

Table 2.–*Viability of dwarf mistletoe seeds exposed to darkness and continuous artificial light*

Days storage 13°C.	Percent viability	
	In light	In dark
	A. ABIETINUM	
0	97	97
32	90	91
60	71	74
89	53	60
120	39	44
135	32	33
	A. OCCIDENTALE	
0	82	82
14	77	78
31	71	76
41	64	71
51	52	55

Relative Humidity

Because dwarf mistletoe seeds are deposited on needles and branches of conifers and are exposed to a natural air environment, the influence of relative humidity on viability was studied. Seeds of *A. abietinum* were exposed to several different regimes of relative humidity at constant storage temperatures of 15°C. and 25°C. Humidity control was obtained with saturated salt solutions (Hodgeman 1951-52; Anonymous, International Critical Tables 1926).

Small, airtight humidity chambers were made from pint mason jars. Each chamber contained a salt solution, a glass cylinder, and a piece of plastic window screen on which the seeds were placed. Seeds to be tested were surface sterilized in 0.1 percent mercuric chloride ($HgCl_2$) for 15 minutes, washed in three changes of sterile distilled water, placed on sterilized pieces of the window screen, and dried overnight in a desiccator. The screens bearing the seeds were then placed on the glass cylinder in the chambers. The chambers were kept in the dark at a constant temperature. Periodically, 100 seeds were removed and tested for viability with TTC.

At both storage temperatures, relative humidity had no significant effect on viability of *A. abietinum* seeds *(table 3)*. The one influence relative humidity did have on seeds in the tests was noticed at 95- and 100-percent humidities at 15°C. At these two humidities some seeds germinated, indicating that free water or a nearly saturated atmosphere provides adequate moisture for germination.

Table 3.–*The viability of seeds of A. abietinum under varying conditions of temperature and humidity* [1]

Days storage	Percent viability at 25°C. and relative humidity of				
	0	33	62	93	100
7	32	21	36	35	33
15	4	7	8	15	6
30	0	0	0	0	0
Days storage	**Percent viability at 15°C. and relative humidity of**				
	0	35	66	95	100
30	40	41	31	[2]34	[2]31
62	28	32	27	[2]39	[2]33

[1]Seeds 60 percent viable at the start of the test.
[2]Percentage of seeds that germinated.

Moisture Content of Seeds

To determine whether or not differences in relative humidity affected the moisture content of the seeds, a further experiment was needed. But first, the amount of free or loosely held water present in the outer viscin layer of fresh seeds had to be determined. To obtain this, seeds were handled in three ways: (a) one lot of seeds was soaked in acetone for 10 seconds to aid in drying, air dried for 5 minutes, and then placed in a desiccator for 24 hours; (b) another lot was placed in a desiccator for 24 hours without pretreatment; and (c) the third lot was air-dried at room temperature for 24 hours only.

Each seed lot was then weighed, oven-dried at 80°C. for 24 hours, and reweighed. The difference between the percent moisture content of the air-dried seeds and the percent moisture content of each of the treated lots of seeds was considered the percent moisture present in the viscin layer.

There was essentially no free water present in the viscin layer of freshly collected seeds air-dried for 24 hours *(table 4)*. Furthermore the treatments had no effect on the internal moisture content of the seeds. On the basis of their oven-dry weight, fresh seeds contained about 35 percent water.

Next, I sought to determine the effect of temperature and relative humidity on the moisture content of seeds of *A. abietinum*. Viability was also tested.

Table 4.—*Moisture content of variously treated dwarf mistletoe seeds*

Seed treatment	Fresh weight per 100 seeds	Moisture Content	Difference from control
	Mg.	*Percent*	*Percent*
Acetone treatment, dessiccation	263.3	36.4	+1.4
Desiccation	255.6	34.5	- .5
Air-drying (control)	257.6	35.0	--

Seeds placed in humidity chambers, as previously described, were exposed to a desiccated atmosphere (0-5 percent relative humidity) and a near-saturated atmosphere (87-90 percent relative humidity). One chamber at each humidity was then stored in the dark at 0°C. and at 25°C. At periodic intervals 100 seeds were taken from each chamber, soaked in acetone for 15 seconds, air-dried for 1 hour to remove surface moisture that may have been absorbed by the viscin layer or may have accumulated on seeds in the chambers. After this treatment, the seeds were weighed, oven-dried at 80°C. for 24 hours, and reweighed. At the same time 100 seeds from each chamber were tested with TTC for viability.

Both temperature and relative humidity significantly affected the moisture content of seeds *(table 5)*. The effect of time was essentially linear. In all chambers, moisture content reached an equilibrium after about 5 days and changed relatively little thereafter. At both temperatures, moisture content of seeds in the near-saturated atmosphere was about two to three times that of seeds in a desiccated atmosphere. As in previous tests, temperature significantly influenced viability, whereas moisture content did not. At each temperature, viability decreased at approximately the same rate, irrespective of moisture content.

Discussion

Viability of freshly collected dwarf mistletoe seeds was found to be consistently high in these studies. Area of seed collection did not influence viability, as has been reported by Bonga and Chakraborty (1968) for *A. pusillum* Peck.

Weir (1918) claimed that under hot, dry conditions, seeds lose viability rapidly as a result of water loss from the endosperm. Results of my study agree with those of Weir in that seeds did not store well under hot, dry conditions. Relative humidity of the atmosphere or moisture content of the seeds, however, did not have a marked influence on longevity. Regardless of moisture content of the seeds, viability decreased with an increase in storage temperature above freezing. At a temperature considerably below freezing, seeds also lost viability very rapidly. Although the theory was not tested, it is possible that at subfreezing temperatures moisture content of seeds may affect viability. Sudden exposure of fresh seeds to extreme cold (-15°C.) may have caused death as a

Table 5.—*The moisture content and viability of seeds of A. abietinum under varying conditions of temperature and relative humidity*[1]

Days storage	0°C.				25°C.			
	0 pct. rel. humidity		90 pct. rel. humidity		0 pct. rel. humidity		90 pct. rel. humidity	
	Moisture content	Viability	Moisture content	Viability	Moisture content	Viability	Moisture content	Viability
	Percent							
5	27	95	49	94	9	50	34	51
13	26	98	50	97	16	38	37	20
21	24	89	49	95	11	24	33	22
29	(2)	(2)	(2)	(2)	14	4	36	8
53	21	90	53	92	(2)	(2)	(2)	(2)
83	21	79	57	89	(2)	(2)	(2)	(2)

[1]Seeds contained 33 percent moisture and were 98 percent viable at the beginning of the test.
[2]No determinations made.

result of the formation of ice crystals in the tissues.

The finding that seeds of dwarf mistletoe retain viability longest at near freezing temperatures agrees with results reported by Scharpf and Parmeter (1962), Beckman and Roth (1968), and Wicker (1967).

Constant exposure to light did not prolong the viability of seeds of either *A. abietinum* or *A. occidentale* as was reported by Heinricher (1915) for *A. oxycedri.* Crocker (1936) points out that Heinricher had published a report on the favorable influence of light on the viability of seeds of the true mistletoe *Viscum album* L. As a result of Heinricher's experience with *Viscum,* it is possible that he erroneously attributed loss of viability to lack of light during storage. In his early experiments, Heinricher was not able to control the temperatures at which his seeds were stored. It is likely, therefore, that unfavorable temperature conditions during storage and not the lack of light were responsible for loss of viability.

The decrease in viability of seeds exposed to sunlight over those stored in the dark in my study was probably the result of solar radiation increasing temperatures above optimum for maximum longevity.

GERMINATION

The literature contains conflicting reports on temperatures favorable for germination and possible requirements of mistletoe seeds for a period of dormancy. Weir (1918) claimed percentage of germination increased in dwarf mistletoe seeds exposed to freezing temperatures. Beckman and Roth (1968) reported that "prolonged chilling" of *A. campylopodum* is actually necessary for germination. On the other hand, Scharpf and Parmeter (1962) found that seeds of *A. occidentale* required no period of chilling, but that adequate moisture and a favorable temperature (13.3°C.) were necessary for germination. The optimum constant temperature reported by Beckman and Roth (1968) for germination of *A. campylopodum* was between 17°C. and 19°C., but the most favorable alternating night-day temperatures for germination were 5°C. to 15°C.

In general, most investigators have found that light is either required for germination of mistletoe seeds or stimulates it to some degree. Studies by Wiesner, as reported in Crocker (1936), showed that light was required for germination of *V. album.* Heinricher (1915) reported light to be necessary for germination of *A. oxycedri.* In a subsequent study (1917), he again tested the germination of *A. oxycedri* in the dark. After 18 days he noted no germination. On the 18th day, seeds were exposed to diffused daylight. After a day in the light, 3 of 19 seeds germinated, 2 of which Heinricher felt undoubtedly must have germinated while in the dark. Scharpf and Parmeter (1962) found that at 13°C. light is not necessary for germination of *A. occidentale,* but stimulates it and slightly increases percentage germination. Kuijt (1960) reported that chlorophyll occurs in the endosperm and radicle of dwarf mistletoe seeds and that these organs undoubtedly are photosynthetically active.

Heinricher (1915) reported that dwarf mistletoe seeds required a chemical stimulus for germination, provided by either living or dead organic matter. In a subsequent study, however, Heinricher (1917) corrected his early statements on germination when he found that seeds germinated on either organic or inorganic materials as long as free water was present.

In laboratory studies with a few North American species of dwarf mistletoes, Gill and Hawksworth (1961) found that removal of the viscin layer surrounding the seeds hastened and improved germination. Beckman and Roth (1968) suggested that a chemical inhibitor associated with the seed covering prevents germination. With time the inhibitor gradually breaks down to a point at which germination will occur if light, moisture, and temperature are favorable. Wicker (1962) reported that hydrogen peroxide stimulated germination of *Arceuthobium* spp.

Standard Germination Test

For the studies of influences on germination of dwarf mistletoe seeds, a uniform method of handling a fairly large number of seeds was needed. Scharpf and Parmeter (1962) described the method for germinating seeds of *Arceuthobium.*

Surface Sterilization

Preliminary germination tests in the laboratory demonstrated that the seeds of dwarf mistletoe are rather slow to germinate, and as a result require special handling to avoid contamination from micro-organisms. For example, freshly collected as well as stored seeds which were not disinfected but placed directly on moist filter paper in petri dishes were overrun with micro-organisms before seeds could

germinate. These micro-organisms, growing profusely on the surface of the seeds, prevented germination. Therefore, several methods were used in an effort to surface sterilize seeds for aseptic germination tests *(table 6)*.

"Clorox,"[4] a commonly-used laboratory disinfecting agent, and propylene oxide, a gaseous sterilizing agent, proved unsuitable for surface sterilization. Mercuric chloride ($HgCl_2$), however, did provide adequate surface sterilization. In none of the tests in which a 0.1-percent solution of $HgCl_2$ was used did contamination occur. Addition of wetting agents (Amphyl[5] or alcohol) and vacuum treatment did not improve sterilization.

Additional tests were conducted to determine if $HgCl_2$ had any detrimental effects on the seeds. Seeds were soaked for 15 minutes in a 0.1-percent solution of $HgCl_2$, washed in three changes of sterile water, air-dried, and stored in petri dishes at 13°C. Control seeds were washed in distilled water only, air-dried, and stored in dishes at 13°C. Periodically, 50 treated and 50 untreated seeds were removed from storage and tested with TTC for viability. The effect of $HgCl_2$ on the viability of dwarf mistletoe seeds was:

	Percent viability	
	$HgCl_2$-treated seeds	Untreated seeds
Days storage:		
0	94	88
13	82	84
28	74	76
47	72	76
64	68	68

Viability decreased linearly with time, and was not affected by treatment with $HgCl_2$. As a result of this information $HgCl_2$ was adopted as the standard sterilizing agent.

A standardized method of handling seeds for germination, based on the results of the previous tests, was adopted.

About 100 dwarf mistletoe seeds were enclosed in a bag made from a 15 cm. square of cheesecloth. The four corners of the cloth were gathered up and wired together to form the bag. In the bag seeds were surface sterilized in 0.1 percent $HgCl_2$ for 15 minutes, washed for 10 minutes each in three changes of sterile, distilled water, and placed in a 100-mm. petri dish. The bag was opened in the dish with sterile forceps and the seeds distributed evenly over the cloth. Sufficient water for germination was present on the cloth and seeds. The dish was then covered and sealed with drafting tape to prevent evaporation of moisture. At periodic intervals, the seeds in the dishes were examined with a dissecting microscope for germination. Seeds were considered germinated when the radicle emerged from the endocarp.

By this method, large numbers of seeds could be handled fairly easily. For the various studies undertaken, the seeds could be either germinated directly on the cheesecloth in dishes or removed from the cheesecloth after surface sterilization and placed on other substrata for testing.

Influences on Germination

Temperature

To determine the effect of constant temperature on the germination of dwarf mistletoe seeds, seeds of *A. abietinum* were surface sterilized, put in dishes as previously described, and exposed to a range of constant temperatures. At each temperature, 100 seeds were used, and all tests were made in the dark. At periodic intervals, the seeds in the dishes were observed for germination.

Temperature affected both the rate of germination and percentage germination *(fig. 3)*. Rate of germination increased with temperature between 0°C. and 13°C. and decreased between 13°C. and 22°C.

Percentage germination did not progressively increase with temperatures above freezing but was

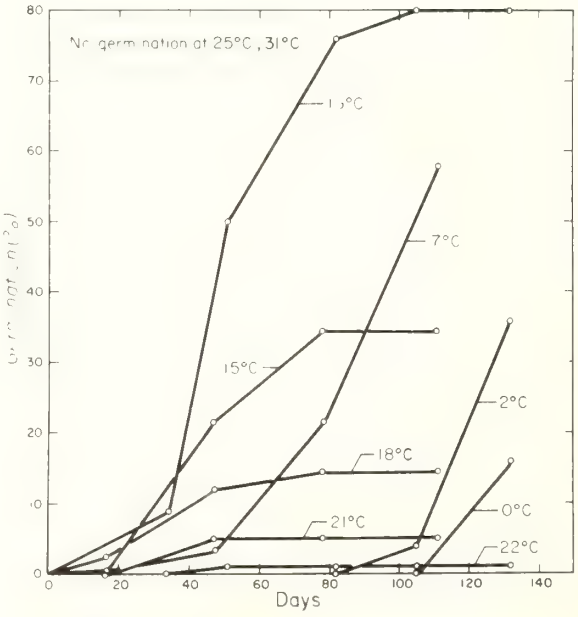

Figure 3.—*Temperature affected the germination of seeds of A. abietinum.*

[4]Trade names and commercial products or enterprises are used solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

[5]See footnote 4.

Table 6.–*Results of surface sterilization of seeds of dwarf mistletoe for aseptic germination, by treatments*

Chemical agent	Strength of active ingredient (percent)	Treatment	Plates used[1]	Plates contaminated with microorganisms after 1 month
Sterile water	--	Three 10-min. washes, sterile water	4	4
Clorox	1	10-min. soak; one 10-min. wash, sterile water	4	4
	1	15-min. soak; three 10-min. washes, sterile water	2	2
	2		2	2
	3		2	2
	4		2	2
	5		2	2
Clorox and amphyl	1	Ditto	2	2
$HgCl_2$	0.1	Ditto	4	0
$HgCl_2$ and amphyl	0.1	Ditto	4	0
$HgCl_2$ and alcohol	0.1	Ditto	4	0
$HgCl_2$ and vacuum	0.1	Ditto	4	0
$HgCl_2$ and amphyl and vacuum	0.1	Ditto	4	0
Propylene oxide	2 cc per 5,000 cc air	24 hours sterilization and 24 hours aeration	5	5

[1]Twenty-five seeds per plate.

highest at 13°C. and decreased above and below this temperature. No germination of seeds occurred at temperatures above 22°C. Some germination did occur at 0°C., but only after about 4 months.

pH

To ascertain the effect of pH on the germination of *A. abietinum* phosphate buffer solutions at a pH of 5, 6, 7, 8, and 9 were used. "Hydrion" buffer capsules were used to make the solutions, one capsule per 100 ml. solution. The solutions were placed in 125-ml. flasks and the flasks plugged with cotton and autoclaved. After autoclaving, the sterile buffer solutions were checked with pH paper and found to be within about ± 0.2 pH of the desired pH. Non-buffered, sterile distilled water at a pH of 6.5 was used as a control. Cheesecloth bags containing 25 seeds each were surface sterilized, washed in sterile distilled water, and then placed in the test solution for one-half hour. Two bags of seeds were used at each pH. After the half-hour treatment the seeds were distributed over the cheesecloth in petri dishes and placed in the dark at 16°C. for germination.

The range of pH from 5 to 9 had no significant effect on the germination of dwarf mistletoe seeds. Germination of seeds in the phosphate buffer solutions did not differ significantly from that of seeds in sterile distilled water. Germination at the pHs tested and in the non-buffered control ranged from about 30 to 40 percent after 3 months.

Influences on Dormancy

Seeds of dwarf mistletoe are reported to undergo a period of dormancy before germinating. Because seeds of some dwarf mistletoes overwinter on hosts and usually are rather slow to germinate in the field, tests were made to determine if they require a period of dormancy for maximum germination. Several methods commonly used to break dormancy were used. These included exposure to light, scarification, after-ripening, removal of germination inhibitors, and chemical stimulation of germination.

Information on dormancy in dwarf mistletoes sheds light on the conditions that influence germination in nature and also facilitates the handling, storage, and germination of seeds in the laboratory.

Light

Previous studies had shown that light was not necessary for germination of *A. occidentale* but suggested that light stimulates germination (Scharpf and Parmeter 1962). Additional tests were made, therefore. Because it was desirable to maintain constant temperatures during germination, the tests were carried out under artificial light in temperature controlled chambers. Temperatures near optimum for germination (13°C. and 16°C.) were used.

One hundred seeds handled as described for germination were used at each temperature and under

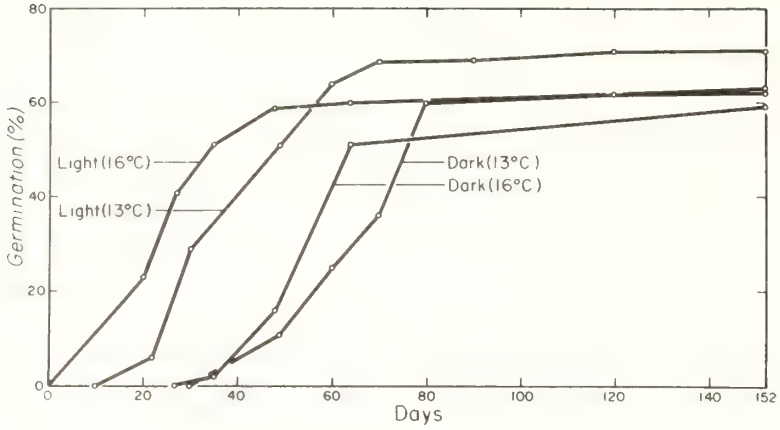

Figure 4.–*Light reduced the time needed for germination of seeds of A. occidentale.*

each light condition. The source of light was a bank of four 40-watt, cool-white fluorescent bulbs. The seeds were exposed to approximately 500 foot-candles of light. At intervals the seeds were examined for germination. At both temperatures, light significantly shortened the time of germination of seeds *(fig. 4)*. Germination began after about a week to 10 days in the light, whereas between 3 to 4 weeks were required for beginning germination in the dark. Percentage germination was greater in the light than in the dark at 16°C. but not significantly different in the light and dark at 13°C.

Scarification

Both mechanical and chemical methods of scarification aimed at making the seedcoat more permeable to water have been used to break seed dormancy (Crocker and Barton 1953). In tests with dwarf mistletoe, both types of methods were used. Dwarf mistletoe seeds have no seedcoat, but I wanted to determine if the viscin layer and endocarp surrounding the seeds inhibit germination by preventing water or oxygen from entering the seeds.

Six bags, each containing 50 dwarf mistletoe seeds, were prepared for seed sterilization. One each of three bags was dipped into acetone, petroleum ether, and a 1-molar solution of ammonium hydroxide for 10 minutes. Seeds in the fourth bag were placed in concentrated sulfuric acid in a petri dish before being placed in the bag, to prevent breakdown of the cheesecloth bag by the strong acid. Before the seeds in the fifth bag were bagged, they had been mechanically scarified by carefully cutting away with a sharp razor blade a small part of the viscin layer and endocarp. The seeds in the last bag were left untreated as a control. The seeds in all bags were then surface sterilized, plated, and placed in the dark at 15°C. to germinate. The seeds were observed at intervals for germination.

Both chemical and mechanical methods of scarification failed to stimulate germination *(fig. 5)*. In the

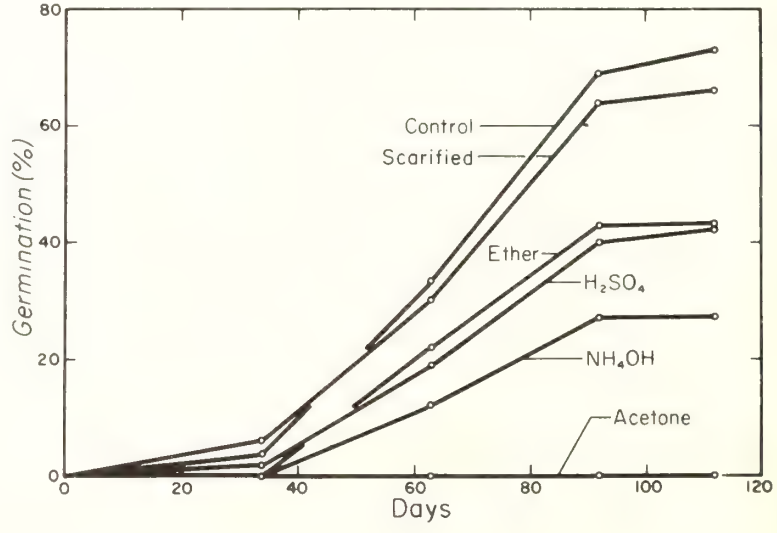

Figure 5.–*Mechanical and chemical scarification did not favorably affect germination of seeds of A. occidentale.*

tests using acetone and ammonium hydroxide, germination was inhibited significantly. In the tests using ether and sulphuric acid, the results were not significantly different from those of the control.

After-Ripening

The seeds of many plants, including a number of the coniferous hosts of dwarf mistoetoe, require a period of exposure to low temperatures during which they undergo certain changes known as after-ripening (Crocker and Barton 1953; U.S. Forest Serv. 1948). After-ripening requirements are often best met by stratification (exposure to moist conditions at low temperatures). But preliminary tests in these studies and in studies reported by Wicker (1967) showed that dwarf mistletoe seeds not handled aseptically became overrun with micro-organisms during stratification and moist cold storage. Tests were made to determine the effect of stratification under aseptic conditions and low-temperature dry storage on the germination of dwarf mistletoe seeds.

Four lots of freshly collected seeds of *A. occidentale,* 100 seeds per lot, were bagged, surface sterilized, and placed on moist cheesecloth in sterile petri dishes. Two of the lots of seeds were then placed in the dark at 13°C. to germinate. The other two lots of seeds were placed at 0°C. to stratify for 2 months. An additional two lots of freshly collected seeds were placed in petri dishes and stored dry 0°C. for 2 months.

After the 2-month period, the stratified seeds, still on moist cheesecloth in petri dishes, were placed in the dark at 13°C. to germinate. At the same time, the seeds stored dry at 0°C. were bagged, surface sterilized, placed in sterile petri dishes, and put at the same temperature to germinate. At periodic intervals the seeds were observed for germination.

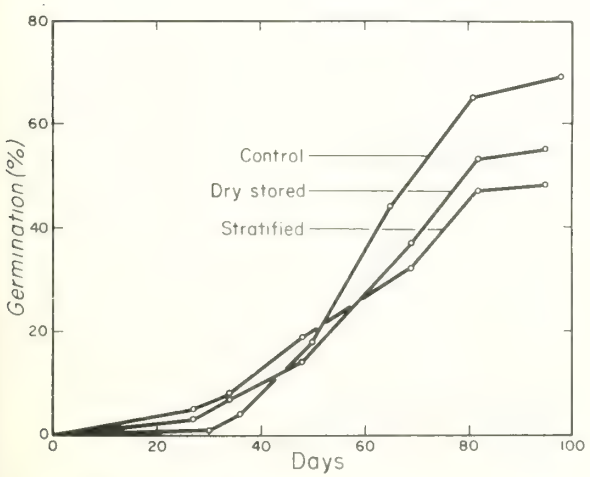

Figure 6.—*Stratification and dry cold storage did not favor germination of seeds of A. occidentale.*

Neither dry storage nor stratification favored the germination of dwarf mistletoe seeds *(fig. 6).* Seeds kept for 2 months for after-ripening under each of these conditions showed a significantly lower percentage of germination than did fresh seeds allowed to germinate immediately. Also, percentage of germination was significantly higher in seeds stored dry than in those stratified. Thus, seeds of dwarf mistletoe do not require a period of after-ripening for germination.

Germination Inhibitors

The fleshy coating of some seeds has chemicals that prevent germination (Crocker and Barton 1953; Evenari 1949). Beckman and Roth (1968) have suggested that certain chemicals might be present in the viscin layer of dwarf mistletoe seeds which prevent germination.

A preliminary investigation showed that the viscin layer surrounding the seeds of dwarf mistletoe is primarily pectic. The presence of pectin was determined by a specific test for pectin based on the reaction of hydroxamic acid with ferric ion (McCready and Reeve 1955).

A study was made to determine if the pectic portion of the viscin coating or any materials contained in the pectic matrix affected germination of *A. occidentale.* To test this, the viscin layer surrounding the seeds was removed before germination with pectic enzymes (Durbin 1956). Durbin used the enzyme pectinase to remove pectic substances surrounding the seeds of cacti. For my study, the pectic material in the viscin layer of dwarf mistletoe seeds was removed with the enzyme polygalacturonase (PG). An attempt was also made to remove germination inhibitors by soaking the seeds in distilled water.

Dwarf mistletoe seeds were placed in bags, for surface sterilization, 100 seeds per bag. Five bags in all were made. Two of the bags were placed in 125 ml. flasks, each of which contained 50 ml. of a 3-percent solution of PG; and two bags were placed in 125 ml. flasks, each of which contained 50 ml. of sterile distilled water. The four flasks were then gently agitated in a biological shaker at room temperature. The seeds in one flask containing PG and one flask containing water were removed from the solutions after 3 hours' agitation, surface sterilized, placed in sterile petri dishes, and placed in the dark at 16°C. to germinate. The remaining seeds in each flask were agitated for a total of 24 hours, removed from the solutions, handled as described above, and stored at the same temperature. As a control, untreated seeds

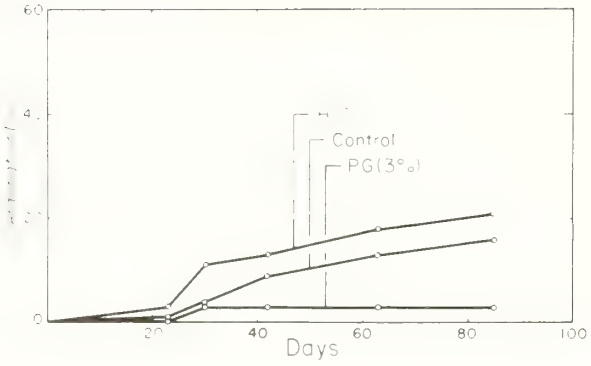

Figure 7.—*After 24-hour treatment with the pectic enzyme, polygalacturonase, seeds of A. occidentale showed a drop in level of germination.*

in one bag were surface sterilized, plated, and stored under the same conditions. The seeds in all plates were examined periodically for germination.

The 3-hour treatment with PG was sufficient to remove the viscin layer. But part of the viscin layer remained on seeds that were treated with water only, for 3 hours.

No significant differences in percent germination were found among the tests using control seeds, untreated seeds, and seeds treated with PG for 3 hours. About 20 percent germination occurred in all the tests after 3 months.

In the seeds treated with PG for 24 hours, not only was all the pectic material removed from the viscin layer but also the endocarp was partly digested from nearly all the seeds. In many seeds a considerable portion of green endosperm was exposed. The viscin coating was also missing from the seeds soaked in distilled water for 24 hours.

Seeds treated with PG for 24 hours showed a significantly lower percent germination than untreated seeds *(fig. 7)*. No significant difference was noted in percent germination for the seeds soaked in water for 24 hours as compared to control seeds.

Chemical Stimulation

Chemicals stimulate the germination of seeds of many plants (Crocker and Barton 1953). The seeds of certain phanerogamic parasites require a chemical stimulus for germination provided by certain species of plants (Srinivasan and Subramanian 1960). Nash and Wilhelm (1960) have found that a plant growth regulator—gibberellic acid—helped stimulate seed germination in two species of the parasitic genus *Orobanche*.

Host Branch Tissue

To test for chemicals in host tissue that may stimulate or suppress germination, seeds of *A. occidentale* were placed on branch segments in agar in petri plates. To prepare the medium, several 1- to 3-year-old branches of Digger pine were cut into segments about 1 inch long and sterilized with gaseous propylene oxide for 24 hours (Hansen and Snyder 1947). After sterilization, 25 segments were placed in sterile petri dishes, five segments per dish. Twenty ml. of 2-percent warm, sterile water agar was then poured into each plate. As the plates cooled, the segments became partially imbedded within the solidified agar. Five plates, each containing 20 ml. agar, were prepared as controls.

Seeds of *A. occidentale* were surface sterilized and placed on the agar plates so that they touched the branch segments. Four seeds were placed along each branch segment. As a control, 100 seeds—20 seeds per plate—were evenly distributed over the surface of the water agar plates. All plates were then held under artificial light at 16°C. At periodic intervals the seeds were examined for germination.

Host tissue had no significant effect on the germination of dwarf mistletoe seeds. About 30 percent of the seeds in both tests germinated after 3 months. Both rate of germination and percent germination of seeds on host tissue were the same as that for seeds on water agar.

Plant Hormones

Studies were made to determine the effect of a plant hormone indole-3-acetic acid (IAA) on the germination of dwarf mistletoe seeds. A sterile stock solution of the hormone was made by first dissolving a known amount of the compound in 5 ml. absolute ethyl alcohol and then adding this solution to 95 ml. sterile distilled water. Serial dilutions were then made from the stock solution to give sterile 100-ml. test solutions at hormone concentrations of 1, 10, and 100 p.p.m. One flask of sterile distilled water was also prepared.

Seeds of *A. occidentale* were placed in bags, 50 seeds per bag, treated by the standard germination method, and washed thoroughly in sterile distilled water. Two bags were then soaked in each of the test solutions for approximately 1/2 hour. The bags were then removed, opened, and placed in sterile petri dishes. The dishes were stored in the dark at 13°C. At periodic intervals the seeds were observed for germination.

Treatment with IAA did not stimulate germination *(fig. 8)*. With IAA at concentrations of 1 and 10 p.p.m. there was no significant effect on germination, whereas at 100 p.p.m. IAA rate and percentage germination were significantly reduced.

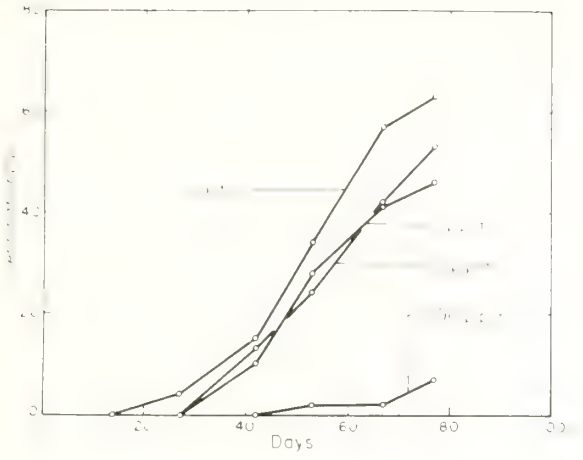

Figure 8.–*Germination of seeds of A. occidentale was not increased by varying concentrations of indole-3-acetic acid.*

Potassium Nitrate

Because seeds of *Arceuthobium* are sensitive to light, a test was made to determine if nitrate (potassium nitrate) would substitute for this response to light, as it has been reported to do for seeds of some plants (Crocker and Barton 1953). Solutions of potassium nitrate at concentrations of 1 normal, 0.1 normal, and 0.01 normal were prepared and 100 ml. of each solution placed in 125-ml. flasks and sterilized by autoclaving. One flask of distilled water was also sterilized and used as a control

Seeds of *A. occidentale* were placed in cheesecloth bags, 100 seeds per bag, surface sterilized, and then soaked in the nitrate solutions for about 1/2 hour. The bags were then opened and placed in sterile petri dishes and then stored in the dark at 16°C. At periodic intervals, the seeds were examined for germination.

Potassium nitrate had a significant effect on the germination of dwarf mistletoe seeds *(fig. 9)*. Seeds in 1 normal potassium nitrate failed to germinate. In the 0.1 normal solution, germination was not statistically different from that of seeds of distilled water. However, a significantly higher percentage germination occurred in 0.01 normal potassium nitrate than in distilled water.

Discussion

The conflicting reports in the literature on the germination of dwarf mistletoe seeds may be due in part to the lack of knowledge about important interrelated variables, such as temperature, moisture, and light, and their influence on germination. Furthermore information about dormancy requirements of dwarf mistletoe seeds has been lacking.

In my studies attempts were made to standardize conditions for germination and also to separate out the various conditions that may influence germination or dormancy.

Temperature was an important influence on germination of dwarf mistletoe, but it did not appear to affect seed dormancy, as reported by Weir (1918) and Beckman and Roth (1968).

The temperature most nearly optimum (13°C.) for germination of *A. occidentale* in the present tests was the same as that reported by Scharpf and Parmeter (1962). This was somewhat lower than the near-optimum constant temperature (17°-19°C.) reported by Beckman and Roth for *A. campylopodum* f. *campylopodum*. It is interesting that their night-day alternating temperature regime most favorable for germination was 5° and 15°C., both of which temperatures are below the optimum constant temperature for germination.

The requirement of light for germination of dwarf mistletoe, reported by Heinricher (1915), was not confirmed in the present studies. *Arceuthobium* is different in this respect from most other genera of mistletoes (Crocker 1936; Gill and Hawksworth 1961). However, light did increase both the rate and percentage germination of seeds, as previously reported by Scharpf and Parmeter (1962). As mentioned earlier, Kuijt (1960) noted that chlorophyll occurs in the endosperm of the seed and in the radicle. Possibly in the light, seeds can carry on limited photosynthesis which stimulates and enhances germination to some degree.

Several other possible influences on dormancy of dwarf mistletoe seeds were tested. These included scarification–both mechanical and chemical; after-ripening–both dry storage and stratification; removal of germination inhibitors in the viscin layer; and

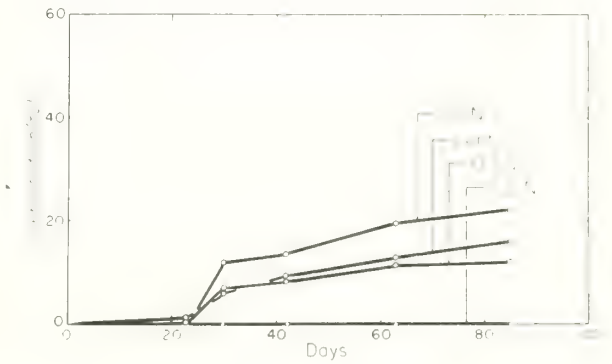

Figure 9.–*Potassium nitrate affected the germination of seeds of A. occidentale.*

chemical stimulation of germination by using host tissue, hormones, and potassium nitrate. In all but one instance—one test with potassium nitrate—germination was either not significantly affected or was inhibited. These results are in contrast with those of Beckman and Roth (1968), who reported a chemical inhibitor associated with the seed coating of *Arceuthobium*. The stimulation of germination by potassium nitrate at the proper concentration may be explained on the basis that this chemical is known to substitute for light in a number of light-sensitive seeds (Crocker and Barton 1953) and may act in the same manner with dwarf mistletoes. Stimulation of germination with hydrogen peroxide for several western dwarf mistletoes, as reported by Wicker (1962) was not tested. This method of using hydrogen peroxide for germination of *A. pusillum* proved unsatisfactory for Bonga (1965).

RADICLE GROWTH AND HOLDFAST FORMATION

The radicles of seeds of mistletoes, including *Arceuthobium*, undergo a period of independent growth between germination and infection of the host. During this period, several stages in radicle development have been reported (Kuijt 1960; Gill and Hawksworth 1961; Scharpf and Parmeter 1967). In general, the developmental stages are (a) an initial stage of linear growth following germination, (b) cessation of linear growth and formation of a "holdfast," (c) production of one or more structures from the holdfast, which penetrate the host.

For the most part only general information is available about the influences on radicle growth and holdfast formation of mistletoes including *Arceuthobium*. Early studies as reviewed by Gill and Hawksworth (1961) have shown that radicles of several mistletoes are negatively phototropic. Negative phototropism has also been reported for several species of dwarf mistletoes (Peirce 1905; Heinricher 1915; Hawksworth 1961). The presence of chlorophyll in the endosperm and radicle (Kuijt 1960) indicates that they are undoubtedly photosynthetically active.

Radicles are reported to continue linear growth until they make contact with an obstacle before initiating a "holdfast" (Hawksworth 1961; Peirce 1905; Scharpf and Parmeter 1967; Weir 1918). Apparently some pressure on the apex of the radicle is necessary before differentiation of the holdfast takes place.

Bonga (1965) reported that radicle growth of *A. pusillum* was not affected by several organic and inorganic media. Addition of host twig extracts also did not stimulate growth, nor was growth affected by changing the pH of the media or soaking the seeds in gibberellic acid.

Bonga and Chakraborty (1968) found that at 15°C., dissected embryos of *A. pusillum* grew more in the light than in the dark, but at 21°C. there was no difference. For "seed cultures," however, radicles grew more in the dark than in the light at both 15° and 21°C. And indole-3-acetic acid (IAA) was found to stimulate holdfast formation on dissected seedlings.

Influences on Growth and Holdfast Formation

To determine the influences on growth and differentiation of the radicles of dwarf mistletoe seeds, a series of tests was made in the laboratory. Specifically, the effects of temperature, light, host tissue, and pH on linear extension of radicles and on holdfast formation were studied.

Pregerminated seeds of *A. occidentale* were used for all tests. The seeds were pregerminated by the standard method described earlier at 13°C. under 500 foot-candles of light for about 1 month. After germination, the seeds were aseptically transferred to a medium on which they were to be tested *(table 7)*.

At periodic intervals during the tests, the seeds were examined for linear growth and differentiation under low power (10X) of a dissecting microscope. Growth of the radicles was measured to the nearest 0.1 mm. with an ocular micrometer; growth was considered to be only the linear extension of a radicle. Radicles that failed to elongate or shriveled up were considered dead, and measurements were stopped. Only radicles with measurable growth were included. The amount of linear extension was assumed to be directly related to conditions favorable for growth. Formation of holdfasts by the growing radicles was also noted.

In all tests, living radicles grew in length during the entire period of observation; no holdfasts were formed on radicles in any of the plates *(fig. 10)*. In those seeds under constant illumination, a negatively phototropic response of the radicles occurred, causing a number of the radicles to penetrate below the

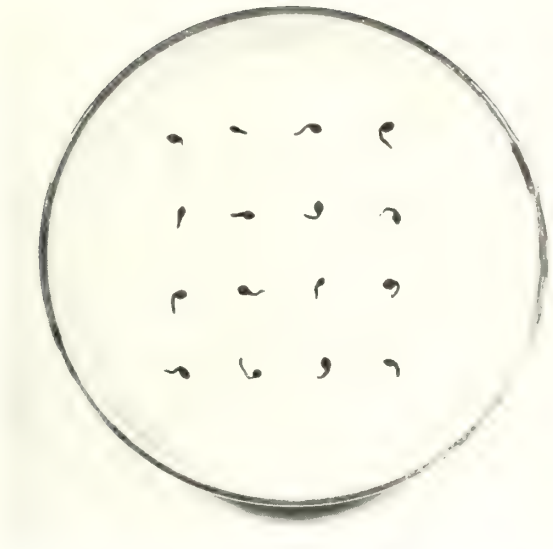

Figure 10.–*Germinated seeds of A. occidentale were grown on water agar in the light at 16°C. for about 2 months.*

surface of the medium. Also, radicles in the light took on a red to red-brown pigmentation.

No similar tropic response was observed for the radicles in total darkness, and these radicles did not become pigmented but remained more or less light green or colorless in appearance. For nearly all seeds in the dark, radicles grew along the surface of the media.

Temperature

Temperature had a noticeable effect on survival of radicles of dwarf mistletoe *(fig. 11)*. In general, radicle survival was inversely proportional to increased temperature. Above 30°C., radicles failed to grow or survive. At 25°C., more than 80 percent of the radicles had died and shriveled up after 39 days. At 19° and 16°C. more than 80 percent of the radicles had died after 90 days. Best survival occurred at 10° and 5°C. Less than 50 percent of the radicles died after 90 days at these temperatures.

Unlike radicle survival, radicle growth was directly proportional to increased temperature *(fig. 12)*. Radicle growth was greatest at 25° and 19°C. (there was no significant difference in growth between these two temperatures). But growth was significantly different between 16° and 25°C. No significant difference in growth was found between 10° and 5°C.; at these two temperatures, however, growth was significantly slower than at 16°C.

Light

Light did not affect the survival of radicles during the test period. Nearly the same number of radicles were alive in the light as in the dark at each temperature.

Table 7.–*Conditions of tests on radicle growth and holdfast formation of dwarf mistletoe*

Test	Test conditions	Medium[1]	Number of seeds
Temperature	Constant temperatures of 5°, 10°, 16°, 19° 25°, 30°, 37°, and 43°C. in the dark	2 pct H_2O agar	2 plates of 16 seeds per temperature
Light	5° and 15°C. in total darkness and under constant illumination (500 ft-c) from cool-white fluorescent bulbs	2 pct H_2O agar	2 plates of 16 seeds under each temperature and light condition
Host tissue	16°C. total darkness	2 pct H_2O agar; host tissue medium, 10 g. pine bark homogenate per 100 cc 2 pct H_2O agar	2 plates of 20 seeds and 1 plate of 25 seeds on each of the test media
pH	16°C. total darkness	2 pct H_2O agar buffered at pH 5, 6, 7, 8, 9 with hydrion phosphate buffer capsules; 1 capsule per 100 cc agar	2 plates of 16 seeds at each pH

[1]Media were autoclaved 15 minutes at 20 p.s.i.

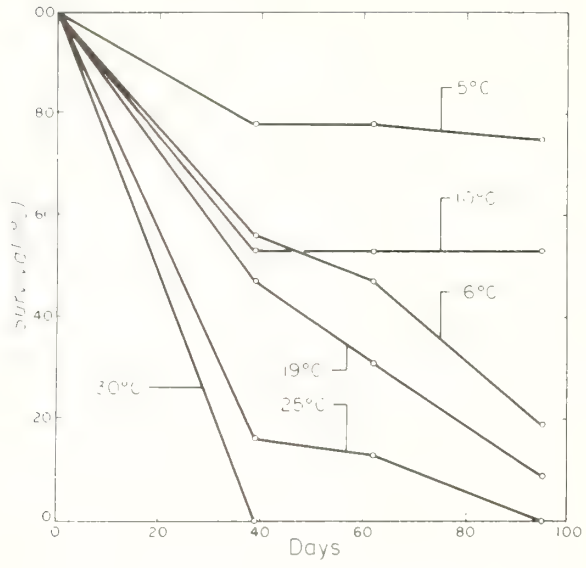

Figure 11.–*Survival of germinated seeds of A. occidentale was adversely affected by increased temperature.*

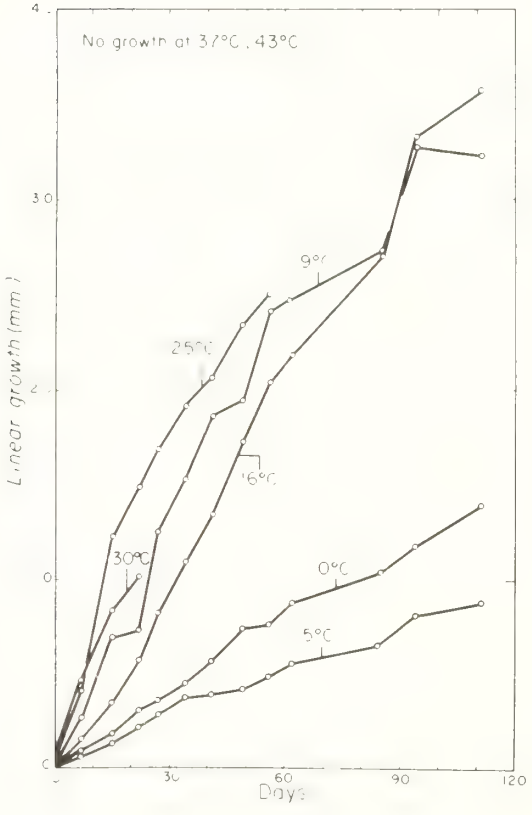

Figure 12.–*As temperature was increased, the linear growth of radicles of germinated seeds of A. occidentale increased.*

At 5°C. no significant difference was found in growth between radicles in the dark and in the light. In general, growth at this temperature was quite slow. However, light favorably influenced linear growth of dwarf mistletoe radicles at 15°C. *(fig. 13).* A significant difference was observed in growth at this temperature; radicles in the light grew about twice as long as those in the dark.

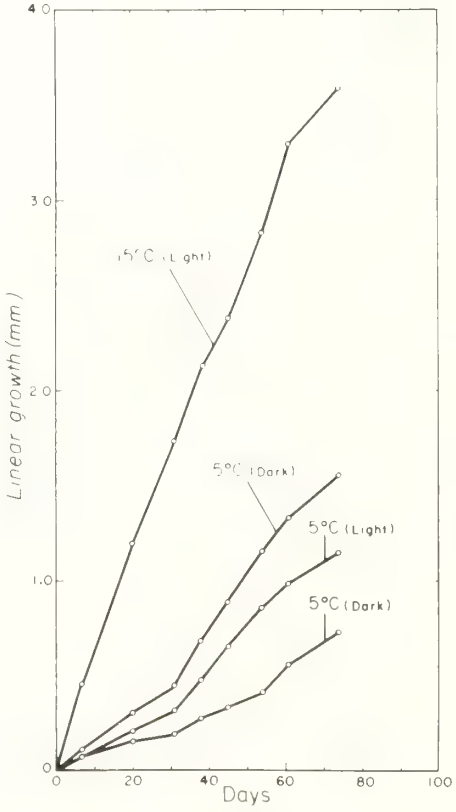

Figure 13.–*Light aided the linear growth of radicles of seeds of A. occidentale.*

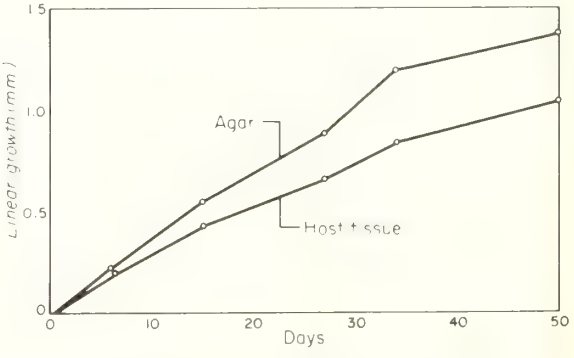

Figure 14.–*The linear growth of radicles of A. occidentale seeds was reduced on host tissue medium.*

Host Tissue

The linear growth of radicles on water agar was significantly greater than that which occurred on host tissue medium *(fig. 14)*. No effect was noticed on the survival of radicles on either medium, however. On both media, most radicles remained alive and in a stage of linear growth during the test period.

pH

The method used to test the influence of pH on growth of radicles was the same as that described for the tests of pH on germination of seeds.

The pH of the medium on which the germinated seeds of dwarf mistletoe was tested had no significant effect on the linear growth of the radicles. Over the pH range from 5 to 9 the growth rate was nearly the same. Radicles had grown 1.0-1.4 mm. in 45 days. pH also had no effect on the survival of radicles. About 80 percent of the radicles survived over the duration of the test period.

Discussion

In the previous tests it was found that the factors that influenced germination also influenced linear growth of radicles.

Radicle growth in general increased in direct proportion to increase in temperatures from 5° to 30°C., but survival decreased in proportion to increase in temperature. Thus, temperatures that favor most rapid growth of radicles may not necessarily be best for maximum percentage penetration and infection of hosts, mainly because of the low survival rate of radicles. Similarly, temperatures best for radicle survival also may not insure maximum percentage penetration and infection because of limited linear growth under these conditions. Probably temperatures most nearly optimum for penetration and infection of hosts by dwarf mistletoes are about midway between temperatures favoring radicle survival and those favoring maximum linear growth.

As with germination, light stimulated but was not required for growth of radicles. These findings matched Kuijt's (1960) observations that radicles are photosynthetically active, but differ from the finding by Bonga and Chakraborty (1968) that radicles of "seed cultures" grew significantly more in the dark than in the light. Strangely enough, some of their dissected embryos grew more in the light than in the dark.

One aspect of the reaction of radicles to light is particularly interesting. Radicles failed to etiolate in the absence of light; thus they reacted physiologically in the same manner as a root. On the other hand, the radicles contain chlorophyll and stomata and morphologically resemble more closely an epicotyl than a root. It appears, therefore, that the structure emerging from the seed and termed "radicle" has features characteristic of both shoot and root.

Results of my studies confirm those of Bonga (1965) in that growth of radicles was not stimulated by host extracts. In fact, in my studies, noticeably less linear growth occurred in radicles on host tissue extract medium than on water agar. Differences in pH as reported by Bonga (1965) and as shown in my studies would not account for these differences in linear growth. Possibly certain natural materials present in host tissue inhibit growth of radicles, but it appears more likely that toxic chemicals released from autoclaved host tissue may have been responsible for reduced linear growth.

Results of my studies confirmed previous reports by Weir (1918), Peirce (1905), Hawksworth (1961), and Scharpf and Parmeter (1967) in that radicles will not form holdfasts unless some obstruction to the linear growth of the radicle is present. An exception to this finding was noted by Bonga and Chakraborty (1968), who found that indole-3-acetic acid (IAA) could stimulate holdfast formation on "dissected seedlings" in pure culture.

SUMMARY

The seeds of *A. abietinum* and *A. occidentale* have a high initial viability, but are relatively short lived and do not survive from one season to the next in the field. Even under nearly optimum conditions for storage (dry at 2°C.) only about half were viable after a year. Initial viability did not vary significantly with regard to year of collection, area of collection, or plant from which collected. Temperature was the most important factor influencing viability of seeds in storage—2°C. was most nearly optimum. Other factors tested, such as light, relative humidity, and moisture content had no effect except that seeds stored moist or at high relative humidities either germinated or became overrun by mold fungi.

Proper temperature and light favored germination of dwarf mistletoe seeds although light was not required. A temperature of 13°C. was most nearly optimum for both rate of germination and maximum percentage germination of seeds. Other treatments used to promote or increase percentage germination, such as varying pH, scarification, after-ripening, removal of germination inhibitors, and chemical stimu-

lation with host tissue or plant hormones, had no appreciable effect.

Radicles of germinated seeds were significantly influenced by temperature. Survival (longevity) of radicles was inversely proportional to temperature above 5°C., whereas linear growth was directly proportional to temperatures between 5°C. and 25°C. Light did not significantly influence radicle survival, but did have a favorable effect on linear growth. The pH and the presence of host tissue had no significant influence on radicle growth and survival.

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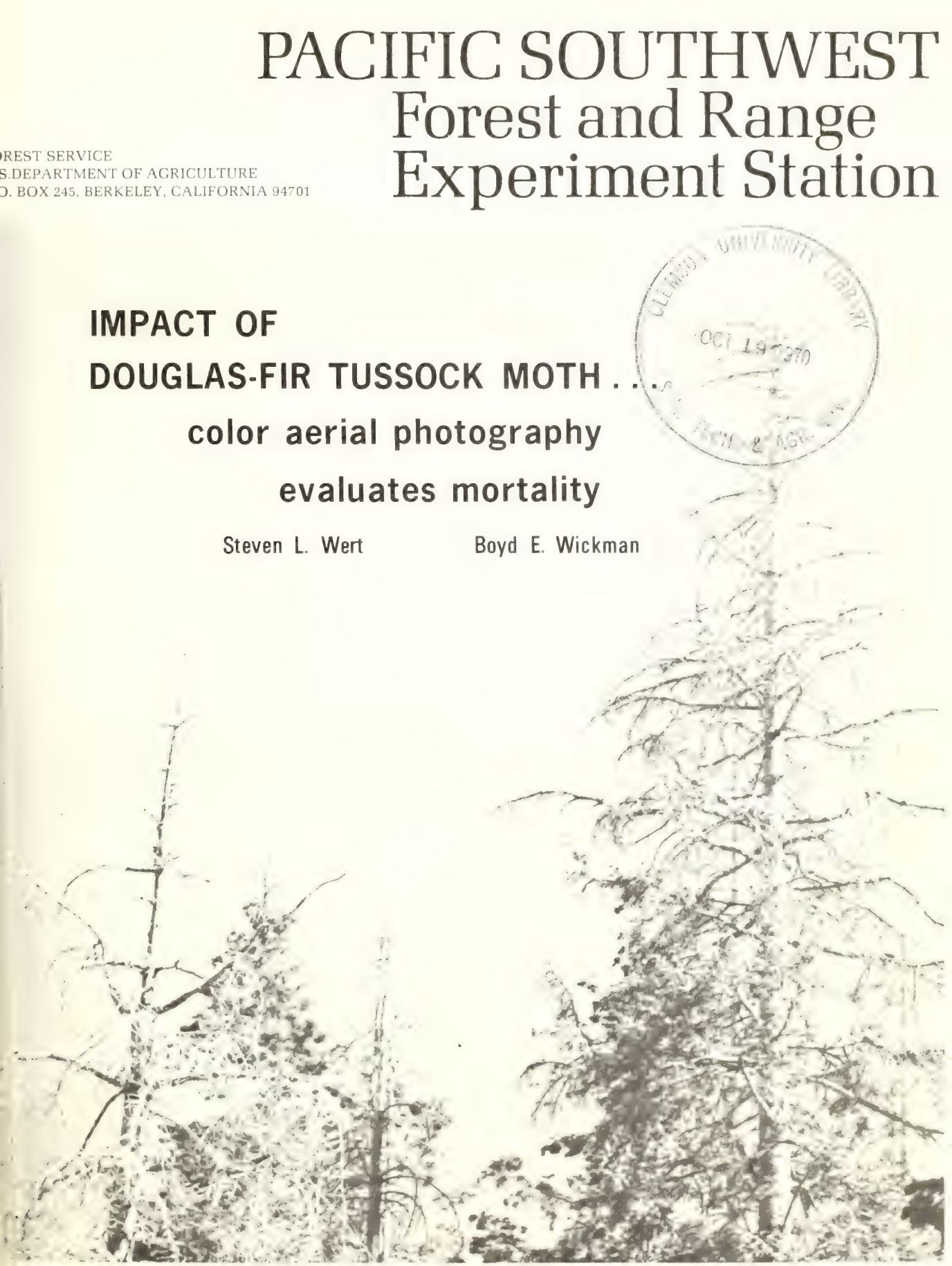
OCT 19 1970

IMPACT OF DOUGLAS-FIR TUSSOCK MOTH . . .

color aerial photography evaluates mortality

Steven L. Wert Boyd E. Wickman



U.S.D.A. FOREST SERVICE RESEARCH PAPER PSW-60 /1970

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The Authors

STEVEN L. WERT, a research forester, is assigned to the Station's remote sensing research unit in Berkeley, Calif. A native of Fort Wayne, Ind., he holds forest management degrees from Pasadena City College (A.A. 1960), Utah State University (B.S. 1963), and Oregon State University (M.F. 1966). He joined the Station in 1966. **BOYD E. WICKMAN**, a research entomologist, was formerly with the Station's forest insect research staff. He is now assigned to the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, with headquarters at Corvallis, Ore.

Figure 1—*Stand of mixed white fir-ponderosa pine forest type near Alturas, California. White patches on hillside are white fir trees defoliated and killed by Douglas-fir tussock moth.*

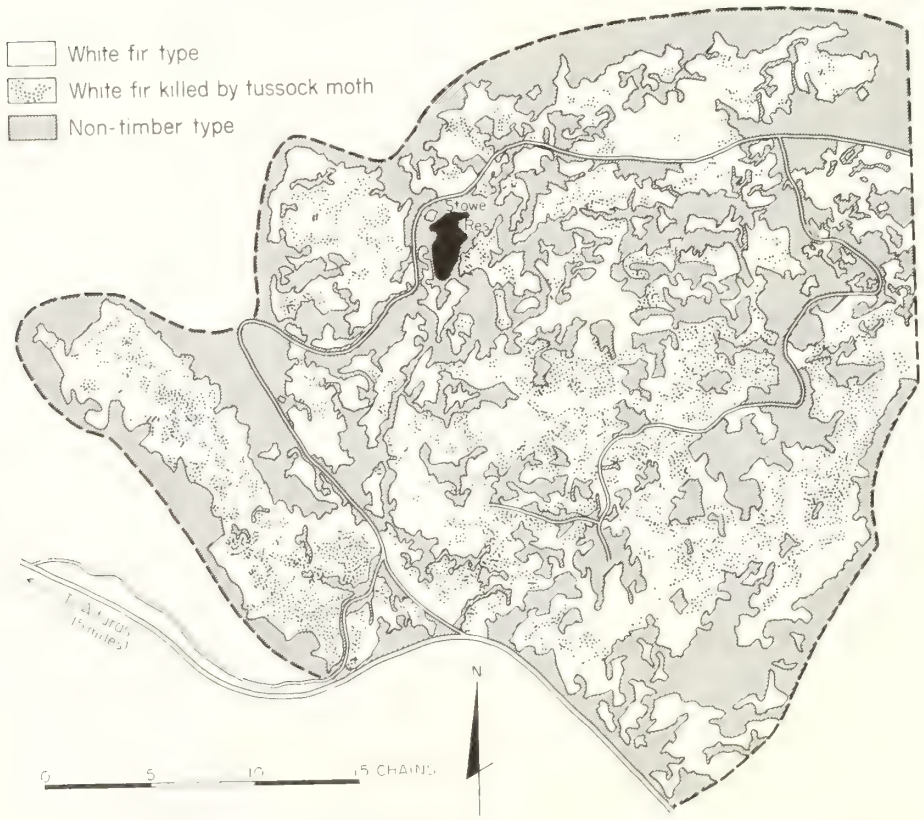

Figure 2—*Location and area of white fir type killed by defoliation from the Douglas-fir tussock moth at Stowe Reservoir. The map was produced from the 1:8,000-scale color photography.*

In 1964-65, the Douglas-fir tussock moth *(Hemerocampa pseudotsugata* McD.*)* caused heavy defoliation of white fir *(Abies concolor* [Gord. and Glend.] Lindl.*)* over thousands of acres of timber stands in northeastern California. Large patches of saplings and pole-sized trees were completely stripped of needles *(fig. 1)*. Trees in areas between these patches were defoliated to varying degrees. Earlier studies have shown that large amounts of tree mortality and top kill can be expected after 2 years of heavy defoliation by the Douglas-fir tussock moth (Wickman 1963) and this infestation bore out the prediction. But large acreages and lack of manpower made a true picture of losses difficult to get with conventional ground survey methods.

Our first thought was to use aerial photography. As a tool in solving land management problems, aerial photography has been accepted for many years. Many films, filters, cameras, and photographic scales are usable, according to specific objectives. We were impressed by results of studies using large-scale color 70-mm. aerial photography to detect insect damage to balsam fir *(Abies balsamea* [L.] Mill*)* in Maine and Minnesota. [1] The type of insect damage (defoliation) and the tree species (balsam fir) closely resembled the conditions we faced.

In 1966, we tested 70-mm. color aerial photography, at a scale of 1:1,584, to determine whether we could detect dead and thin-crowned white fir trees (Wert and Wickman 1968). Correlations were high between photo interpretation of tree crown condition and field examination of the same trees.

Encouraged by these results, we decided to test in 1967 an aerial photo technique operationally by thoroughly sampling a small infestation unit. This paper describes the test and appraises the accuracy, economy, and practicality of the technique for evaluating white fir damage from Douglas-fir tussock moth. Specific objectives of the test were as follows:

1. To test operationally large-scale 70-mm. aerial photography as a method of measuring white fir mortality and crown condition after defoliation by the Douglas-fir tussock moth.

2. To examine the use of small-scale (1:8,000) 9-by 9-inch format color aerial photographs to map and stratify insect damage and lay out flight lines for subsequent large-scale (1:1,584) sample aerial photography.

TEST AREA AND DAMAGE

The test area, Stowe Reservoir, is 1 mile east of Cedar Pass in the Warner Mountains of Modoc County, California. The infestation here covers 450 acres in a moderately sloping basin with mainly south and east exposures. The elevation varies from 5,600 to 6,200 feet, with higher elevations and rugged terrain immediately to the north and west. The second-growth stand is predominantly white fir with a scattering of ponderosa pine *(Pinus ponderosa* Laws.*)*, Washoe pine *(Pinus washoensis* Mason & Stockwell*)*, and western juniper *(Juniperous occidentalis* Hook*)* at the lower elevations and southern exposures. The original stand was predominantly pine and was heavily logged 60 to 70 years ago. It was logged a second time for the fir overstory 16 years ago. White fir of sapling and pole size is now the predominant species type and is growing in scattered patches throughout the area.

Defoliation by the Douglas-fir tussock moth was first noticed at the Stowe Reservoir Forest Service campground early in summer of 1964. By fall it was obvious that a serious tussock moth infestation had developed on about 450 acres concurrently with similar infestations totaling about 80,000 acres on other areas of the Modoc and Lassen National Forests. The infestation was controlled by DDT spray and natural causes, but not before many of the white fir trees were seriously defoliated by tussock moth larvae in 1964. Many of these trees subsequently died or suffered top dieback in 1965.

[1] Aldrich 1966; Aldrich and Drooz 1967; Heller, *et al.* 1967; Weber 1965.

METHODS

Obtaining Aerial Photography

A two-stage aerial photographic technique was used in the study. In the first stage, we obtained small-scale (1:8,000) aerial photography over the entire area of study. Anscochrome D/200 color film was exposed in a K-17 Fairchild aerial camera (9- by 9-inch format).[2]

After the film was developed, areas of contiguous white fir damage were outlined directly on the transparencies. This procedure allowed us to produce a map delineating the damaged white fir stand *(fig. 2)*. From this map we planned our second-stage large-scale coverage (sampling photography) and the ground cruise needed to obtain "ground truth" data.

Large-scale (1:1,584) aerial photographs were obtained for four flight lines, flown by using a Maurer 70-mm. aerial camera with Anscochrome D/200 color film *(fig. 3)*. Total coverage of the sample photography amounted to about 12.5 percent (75 acres) of the study area *(fig. 4)*. This film was processed and returned to the field in about 5 days.

Gathering Ground Data

The previous delineation of contiguous areas of infestation on small-scale photography defined the size of the infestation. We imposed a systematic ground cruise over the area, with cruise lines spaced at 5-chain intervals. This was done so that four of the cruise lines coincided with the flight lines of the large-scale photographic coverage.

Ground crews sampled the area 1/40-acre circular plots established at 2-chain intervals along the cruise lines. Data gathered from the plots served two purposes. They established ground truth for aerial photo coverage, and they provided sample data for an estimate of total white fir damage in the area, taking the place of a 100-percent cruise.

Within each 1/40-acre plot we recorded the following data:

1. D.b.h. of all trees
2. Species
3. Crown condition (alive, dead, thin, or normal, and length of top kill if present)
4. Crown class (dominant, codominant, intermediate, or suppressed)
5. Basal area per acre of live and dead white fir trees (as determined by a 360° sweep of a 40-Basal Area Factor (BAF) optical prism from the plot center)
6. Year of death if caused by tussock moth or secondary insect attack.

Along the cruise lines covered by the large-scale aerial photography, the plots were viewed stereoscopically on the film by means of a portable light table. The location of each plot center examined on the ground was pinpricked on the film. All white fir trees within the plots and visible on the film strip were circled and numbered on a transparent acetate template placed over the film. This provided a count of visible fir trees to compare later with counts made by photo interpreters in the office. Time studies for use in evaluating efficiency were made for each phase of the field operation by a third crew member.

Interpreting Photos

Before photo interpreters looked at the actual plot transparencies, they were trained extensively in identification of tree crown conditions. Stereograms with descriptive commentaries were used to present examples of trees encountered on the infested areas. Interpreters spent about 8 hours studying the stereograms before they began work. The interpreters were also given a tree species identification test from extra coverage film of the same area. Both interpreters were able to identify white fir and associated species within acceptable limits of accuracy.

At each plot location pinpricked on the large-scale 70-mm. photography, the limits of the plot boundaries were plotted on clear acetate templates. Each plot was indexed as to the flight line on which it occurred and numbered in consecutive order. The film was then examined by two photo interpreters.

The photo interpretation procedure was as follows:

1. Each interpreter recorded on a prepared form *(fig. 5)* the tree crown condition of each white fir tree occurring on the plots. Tree crown condition was classified as alive, dead, thin or normal, as for ground data. Top killing was also recorded if it was evident, and the length of the killed top in feet was estimated.
2. All white fir trees interpreted were circled and numbered on the templates prepared, according to the number and description of the trees as recorded on the form.

When photo interpretation was completed for all plots, the resulting data were compared with data gathered in the field.

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[2]Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

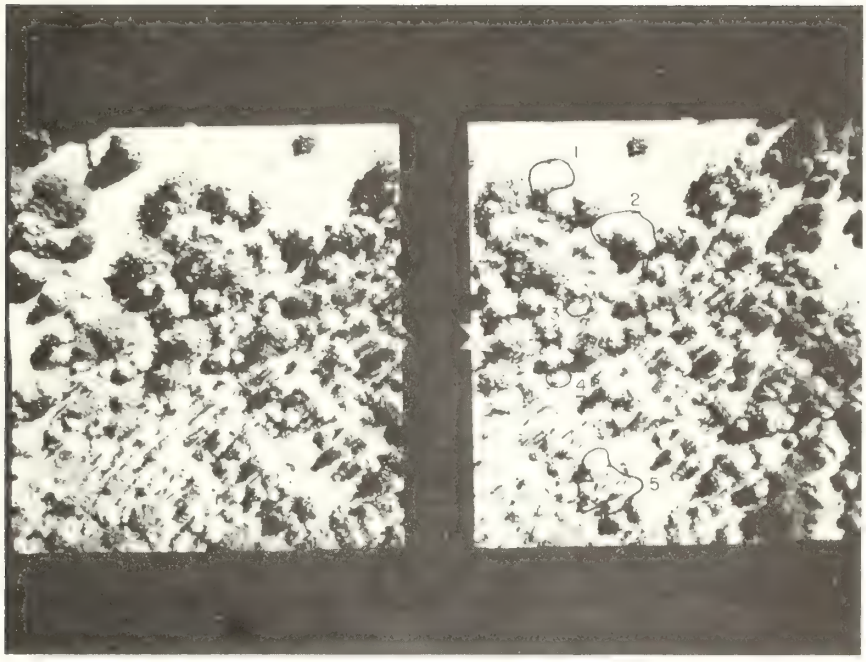

Figure 3—*Example of large-scale aerial photography (stereogram) showing white fir mortality from Douglas-fir tussock moth, was photographed in August 1967, at scale of 1:1,584.*

1. White fir about 50-60 feet high. Top kill about 20 feet with very thin crown in lower two-thirds of crown. Notice that it is overtopping a green tree on the right.
2. Healthy white fir trees.
3. Two dead white fir trees.
4. White fir, thin top, about 15 feet high.
5. Group of 12 dead white fir trees.

Figure 4—*Area covered by the second stage 70-mm. photography at 1:1,584 scale. Four flight lines covered 75 acres.*

RESULTS AND DISCUSSION

Data were compared and analyzed to answer two basic questions: (1) Is there close correlation between photo and field observations of tree crown condition? (2) Is it possible to estimate by aerial photo technique white fir losses in terms of number of trees per condition class (alive, dead, top-killed) within acceptable limits of accuracy on an operational survey basis?

Correlations of Photos and Ground Truth

For each category of tree crown condition a correlation coefficient (r) was calculated between photo observations and ground truth. The correlation coefficient in this work and in similar work done the previous year was:

Crown condition:	Correlation 1967	1966
Dead	0.95	0.98
Alive	.81	.85
Thin	.78	.70
Top-killed	.78	.54

Interpreters were consistent in performance through both years. The differences in correlation between the two years are slight and not significant with one exception—the increase in correlation for

TUSSOCK MOTH DEFOLIATION STUDY - PHOTO INTERPRETATION FORM

Plot No. 2-3 Location STOWE RESERVOIR Time ended 11:10

Flight line 2 Time begun 11 00

P.I. by GREENTREE Date 11-67 Elapsed time 10 min.

Tree No.	Crown class	Tree condition: Alive	Tree condition: Dead	Foliage present: Thin	Foliage present: Normal	Top-kill (feet)	Crown diam. 1/	Total Ht. 1/	Foliage color--(gray,yg, y,r,b)	Cause of death 2/: T.m.	Cause of death 2/: Other
1	1	✓		✓		10					
2	1	✓									
3	2		✓							✓	
4	1										
5	3	✓		✓		2					
6	1		✓							✓	
7	4		✓							✓	
8	2	✓									
9	1	✓		✓		1					
10	2		✓							✓	
11	1		✓							✓	
12	3	✓		✓							

1/ Only for volume estimates. 2/ From field notes.

Figure 5—*Form used during photo interpretation of the large-scale (1:1,584) 70-mm. photography. Measurements of crown diameter and total height were not made on this survey but could be made for larger trees to give volume estimates of mortality.*

the crown conditions "top-killed" and "thin." We believe this increase was a result of the more extensive training given interpreters in 1967. During the photo examinations of 1966, interpreters were given few examples of top-killed or thin-topped trees to associate with observations made during their examination of the study sites. In 1967, however, extensive training was given in the recognition of these categories of tree crown condition. We feel it is important that interpreters recognize these categories. Trees that are top-killed or thin-crowned suffer a serious reduction in growth.

Comparison of Field and Photo Cruise

Data from the sample field cruise provided an estimate of the number of white fir trees killed in the area of Stowe Reservoir.

From the field and photo data, we computed a regression equation for each interpreter to provide an aerial photo estimate of tree mortality. The regression equation for interpreter No. 2 was slightly better than for interpreter No. 1 because of the lower standard error of estimate *(fig. 6)*. The resulting predicted values from both interpreters are compared with the field estimate of mortality in table 1.

The results show that in this test the photo estimate of mortality was comparable to the field estimate. Photo estimates of top-killed, thin-crowned, and live trees were also comparable *(table 2)*.

Only a 100-percent cruise of the area could yield an accurate account of mortality and damage. However, such an undertaking would be impractical for large infestation areas such as this. This study shows that estimates of white fir mortality and tree condition can nevertheless be made from large-scale sample aerial photography so as to be comparable with estimates obtained with an extensive ground cruise such as we undertook here.

Comparisons of photo and ground estimates would not be complete without consideration of the time required to produce each estimate.

The average time spent per plot evaluating white fir condition was 9 minutes for photo interpretation and 27 minutes for the ground cruise. This includes

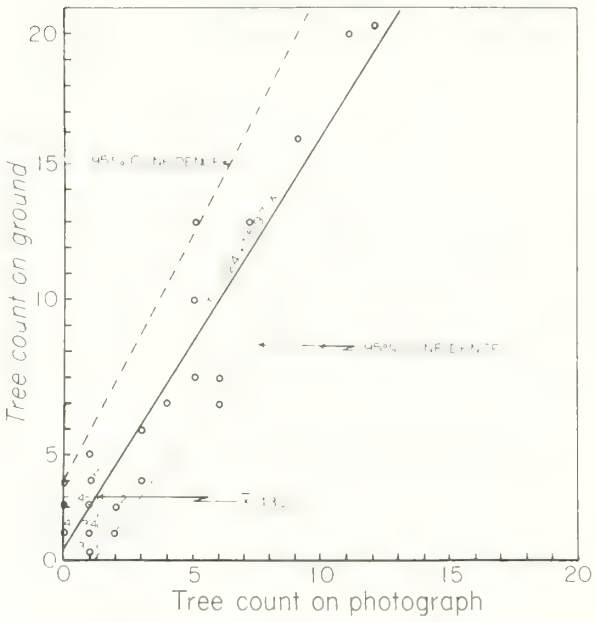

Figure 6—*Plotting of regression equation y = 0.24 + 1.597X in which X is the number of dead trees counted on the photo.*

Table 1.—*Comparison of field and photo estimates of white fir mortality*

Source of estimate	Estimate of dead trees per acre[1]	Regression equation[2]
Field cruise	105.60 ± 7.6	- -
Photo interpreter 1	111.60 ± 8.6	y = -0.42 + 1.454x
Photo interpreter 2	111.44 ± 8.1	y = 0.71 + 1.597x

[1]Standard error of estimates at ± 1 S.D.
[2]Value x is number of dead trees counted on the photo.

Table 2.—*Comparison of field and photo estimates of white fir tree condition*

Crown condition	Estimate of trees per acre[1]		Regression equation for photo estimate[3]
	Field	Photo[2]	
Top-killed	50.27 ± 17.4	58.21 ± 17.2	y = 0.49 + 0.26x
Thin-crowned	96.11 ± 8.0	119.41 ± 18.0	y = .41 + .51x
Live	214.23 ± 11.6	252.52 ± 21.0	y = 1.52 + .67x

[1]Standard error of estimates at ± 1 S.D.
[2]Averages for two photo interpreters.
[3]For each class, value x is number of such trees counted on the photo.

setup time, note-taking, and travel between plots. To complete the ground cruise and compute the estimate required 60 man-hours. The photo cruise estimate was available in 20 man-hours. The photo cruise thus represents about a 67 percent savings in man-hours to obtain comparable mortality data on white fir.

This study shows that large-scale color aerial photography has value as part of a sampling technique to evaluate insect-caused mortality in white fir stands. More elaborate statistical sampling schemes incorporating double sampling with regression or probability sampling would be appropriate on larger acreages. Besides being adaptable to many statistical sampling schemes, this aerial photographic technique has other significant advantages:

- One man can efficiently perform a mortality cruise on a number of photo plots. To be as efficient on the ground, at least two men would be required.
- Aerial photography supplies a permanent photographic record of a particular date and set of stand conditions. This allows further, more detailed examination of plots at the convenience of the investigator.
- The technique as described in this paper is not out of reach financially for the forest manager. The cost of such surveys in dollars spent for labor is either less than or equal to that of field surveys taken to estimate losses. For larger areas the savings may be greater than the 67 percent figure quoted earlier. And the efficiency of such surveys would increase on larger acreages.

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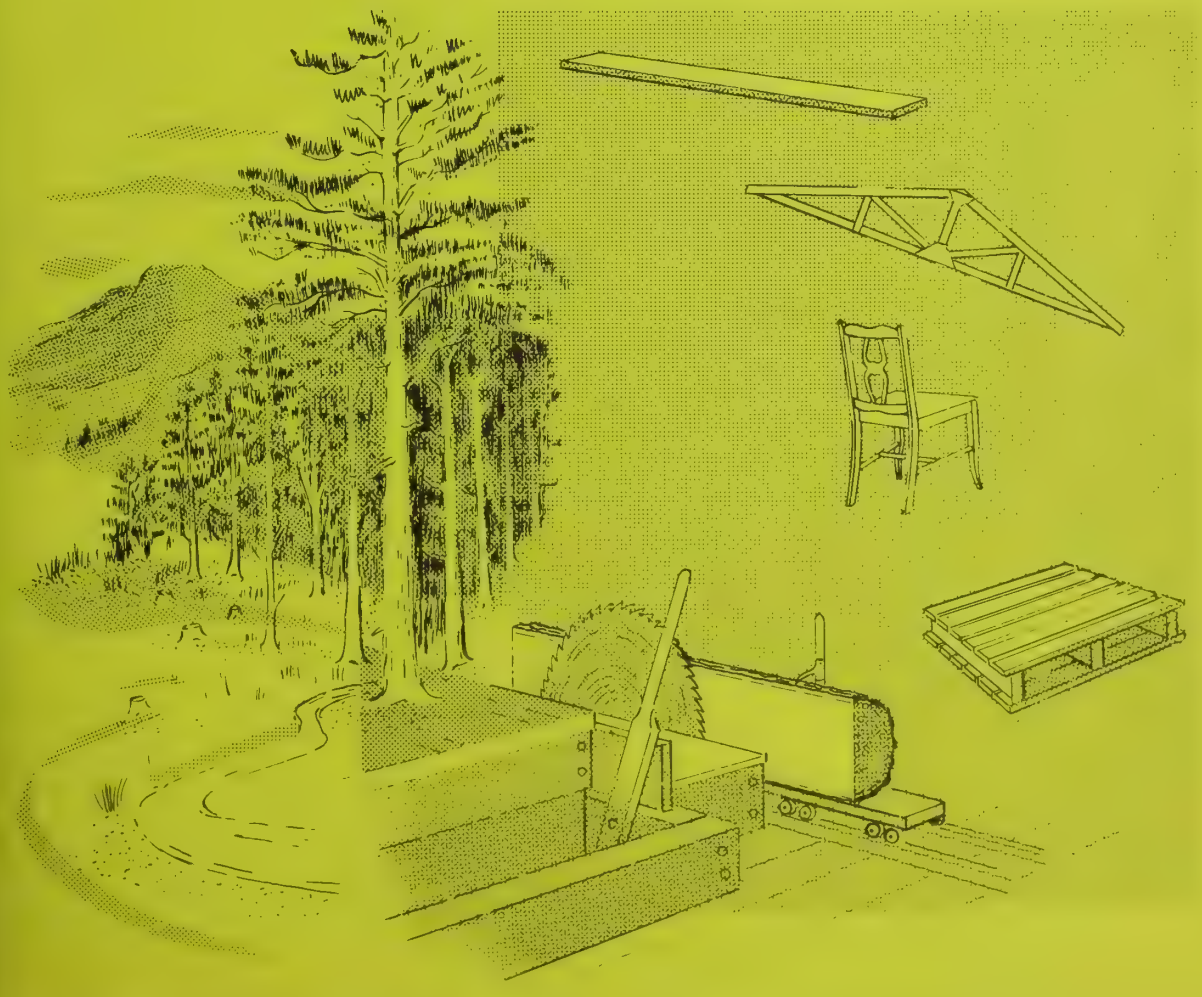
Opportunities for Marketing Hawaii Timber Products

George B. Harpole



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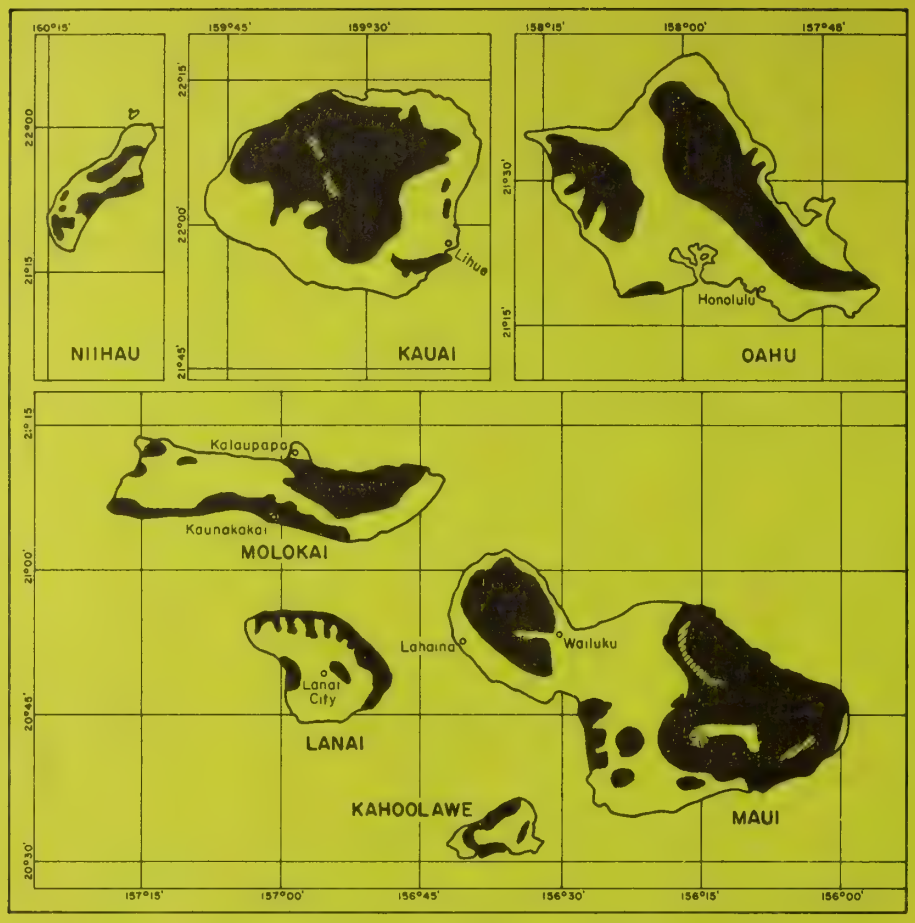

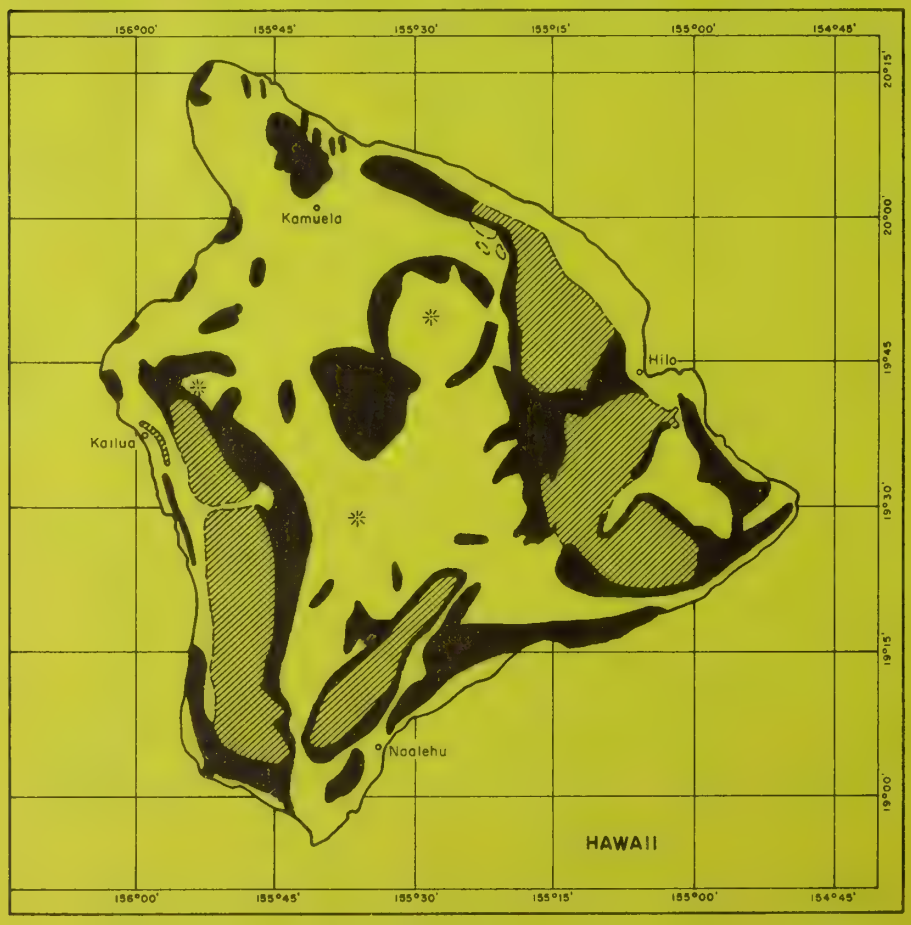

MAJOR FOREST TYPES IN HAWAII

COMMERCIAL

NON COMMERCIAL

Non-forest land

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U.S. Forest Service research in Hawaii
is conducted in cooperation with
Division of Forestry
Hawaii Department of Land and Natural Resources

Foreword

Marketing research has been needed to appraise the opportunities for expanding the Hawaii forest products industry. To provide the basis for this marketing appraisal, facts have been needed about existing resources, reforestation potentials, prospects for expanding present wood products manufacture, and opportunities for introducing newer manufacturing technologies. To gather this information, a Forest Survey was started in Hawaii in 1958, followed by a program of marketing research in 1963. Both programs have been cooperative efforts between the Forestry Division of the Hawaii Department of Land and Natural Resources, and the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Harry W. Camp, Assistant Director, and George D. Frazier, Project Leader, of the Pacific Southwest Forest and Range Experiment Station, provided the leadership and direction for marketing research. Robert E. Nelson, Director of the Station's Institute of Pacific Islands Forestry, supervised the Hawaii forest survey. Special acknowledgments are due the research personnel that have participated in these programs of survey and marketing research, including: Roger G. Skolmen and R. Sidney Boone, research foresters, of the Station's Institute of Pacific Islands Forestry; and John H. Weber, Kenneth D. Mackenzie, and John D. Zinnikas, economists, Pacific Southwest Forest and Range Experiment Station.

The Author

GEORGE B. HARPOLE has been an economist with the Station's forest products marketing research staff since 1967. He earned a B.S. degree in business administration at Montana State University (1959), and has done graduate study in forest economics at the University of California. He began his career with the wood products industry in California as a wholesale lumber salesman, and later worked as a sales and marketing analyst for the wood products division of Potlatch Forests, Inc., San Francisco, Calif.

Traditionally dependent on a narrow economic base, Hawaii has tried to broaden that base through diversification. Its efforts have led to a new appraisal of its forest resources, calling for a change in the traditional way of looking at forest lands. In the past, these lands were treasured almost solely for their influence in protection of watersheds. Besides this important benefit, forests now need to be considered for other products—including wood as a basis for a new industry.

Because of the growing interest in these other products, the Hawaii Department of Land and Natural Resources in 1962 published a multiple-use program that set up policies for managing water, timber, livestock forage, recreation, and wildlife habitat. The program outlined a 10-year plan that includes provisions for tree planting and building of access roads (Hawaii Division of Forestry 1962).

The State has moved cautiously in the development of timber management programs because of problems in the allocation of limited funds and the need for marketing information to guide investment. As Governor John A. Burns stated in his 1963 message to the Hawaii State Legislature:

> The tree planting program was initiated without the benefit of a comprehensive market potential study. To ease this doubt and to put the long-range tree planting program on sounder footing, it is urged that a market potential survey of locally grown hardwoods be undertaken first . . . This study should explore short and long range market demand for locally grown hardwoods.

The Legislature followed up by appropriating funds for a series of marketing studies. The Pacific Southwest Forest and Range Experiment Station was asked to study the forest resources of Hawaii and report on the marketing opportunities for Hawaii-produced timber products. A number of these studies have since been completed.

This paper brings together the major findings of these earlier studies and supplements them with later information. It outlines the opportunities for marketing Hawaii timber products in the State and on the United States mainland. It describes the conditions that wood products manufacturers will need to meet, and the steps industry and the State ought to take to assure an adequate timber supply from which products may be manufactured and marketed.

The Forest Resource

Among the variety of benefits provided by Hawaii's forests the most important are the watershed values. Forests are so vital to the water supply cycle that without them water would become an extremely scarce commodity. For this reason, Hawaii has, since the late 1800's, pursued a policy fundamentally dedicated to the protection of forests for their watershed values (Frame and Horwitz 1965). But in recent years, Hawaii's rapidly exanding population has intensified the need for the many other benefits that the forests could provide. One result has been the start of a long-term and critical evaluation of the State's forest resources.

Commercial Forest Lands

The most beneficial uses of forests are not always related to the opportunities for increasing commercial supplies of timber. Good management is directed towards obtaining the most beneficial combinations of product and service uses from the land (Hawaii Division of Forestry 1962). Under such a policy the forests of Oahu have been considered best suited for watershed, recreation, wildlife, and esthetic values. Most of the land where the production of commercial timber is consistent with a "best use" is on the islands of Hawaii, Kauai, and Maui (Nelson and Wheeler 1963). Large parts of these islands have been designated

as "commercial forest land"—areas suitable for growing timber and with some forest cover but not necessarily stocked with timber trees.

Of the 1,089,000 acres of commercial forest land in Hawaii, the State owns nearly 45 percent. An additional 290,000 acres of extensively grazed lands are also suited for growing timber crops, but now have no forest cover. Native forests in Hawaii are essentially static in terms of annual increases. In the unmanaged native forests, trees must fall from the damage by termites or rot, be blown over, or be harvested before new growth can appear. Unmanaged forests can often be converted to impressive levels of annual yields through good forest management practices. Exceptional sites have been found that can produce close to 4,000 board feet of timber per acre per year. This rate is three to four times the normal rate of growth found among stands of timber growing on the United States mainland (Pickford and LeBarron 1960). More typically most stands of Hawaii plantation timber produce annual increases closer to 1,000 board feet per acre (Nelson and Honda 1966).

If Hawaii's commercial forests could be managed to produce as little as 500 board feet per acre per year, they could support the annual production of at least 500 million equivalent board feet of wood products. More conservatively, 100,000 acres of commercial forests could support a wood products industry capable of producing between 50 and 100 million equivalent board feet of wood products each year. The industry would then rank among Hawaii's most important manufacturing industries.

Plantations

A variety of tree species have been successfully introduced to the Hawaiian Islands. About 800 tree species were recorded as being planted by the State of Hawaii between 1908 and 1960 (Nelson 1965). Several varieties of hardwoods and softwoods introduced to Hawaii are well suited for plantations, and for wood products manufacture.[1] Because of the variety of species that can be grown and their prodigious growth rates the future contributions of commercial forests will depend greatly upon how well tree planting and stand improvement programs match future timber supplies with future demands and manufacturing technologies.

Hawaii commercial forests hold about 852 million board feet of sawtimber *(table 1)*. Including sawtimber and smaller size trees the total growing stock amounts to about 239 million cubic feet.[2, 3] In addition, current plans provide for the planting of about 13,500 acres of State owned land through the period from 1967 to 1971 (Landgraf 1966).

[1] Gerhards 1964; Gerhards 1965; LeBarron 1962; Skolmen 1968a, 1968c; Smith 1960; Youngs 1960.

[2] Honda, Wong, and Nelson 1967; Nelson and Honda 1966; Nelson, Wong, and Wick 1968; Wong, Honda, Nelson 1967; Wong, Nelson, and Wick 1968.

[3] Sawtimber is defined as "live trees of commercial species of at least 11 inches diameter at breast height which contain a butt half-log, or a log which meets the specifications of standard lumber, or tie and timber log grades." Growing stock is more inclusive, being defined as "live trees of good form and vigor, and of species suited for industrial wood." Growing stock included sawtimber trees, poletimber trees, saplings and seedlings that show promise of becoming sawtimber trees.

Table 1—*Volume of sawtimber on commercial forest land, by species group and island, Hawaii, 1961*

Species group	Kauai	Oahu	Molokai	Maui	Hawaii	All islands[1]
	Thousand bd. ft. (Int. ¼-in. rule)					
Ohia	6,165	2,142	22	7,796	361,430	377,555
Koa	4,293	1,684	–	3,517	111,414	120,908
Silk-oak and other[2]	5,571	2,366	–	2,827	47,211	57,975
Plantation types[3]	26,858	45,826	12,600	94,247	116,843	296,374
All	42,887	52,018	12,622	108,387	636,898	852,812

[1]Excluding Niihau, Lanai, and Kahoolawe.

[2]Includes Monkey-pod.

[3]Planted, mainly eucalyptus spp., but includes other hardwood and conifers (see Appendix).

Native forests on the island of Hawaii, top, *include about 360 million board feet of ohia. Saligna eucalyptus trees at Kalopa,* right, *illustrate the wide range of tree sizes found in plantation forests. Eucalyptus robusta stand on Maui,* bottom; *about 200 million board feet of this species are found in plantation forests in the State.*

Norfolk-Island-pine, top, *is one of the many varieties of Hawaii timber well suited for wood products manufacture. The "ribbon" grain,* left, *seen in the lower left piece of koa also commonly appears in robusta lumber. Ebony billets,* bottom, *are imported for manufacture into carvings and other quality hardwood products as a complement to domestic hardwoods.*

Manufacturing Opportunities

Wood Products Industry

Opportunities for wood products manufacturing in Hawaii depend upon the quality and volume of timber production that can be developed in the State. In turn the value of this timber will depend upon the success of wood products production. Single-product operations are often desirable for the purpose of achieving the economies of large-scale production. The distribution of timber between different islands and the limitations of local markets, however, create serious problems for establishing large-scale or single-product forms of manufacturing. The U.S. Forest Service's Forest Survey has defined the working circles of the islands of Hawaii, Kauai and Maui, but none of them offers a sufficient base for the size of "large-scale" operations typically found on the mainland. To combine or operate one working circle with another normally creates transportation or other problems that are only minimal within the boundaries of each working circle (Holt and Nelson 1959; Malcolm 1960). But to manufacture lumber, plywood, or other wood products efficiently, some resources may have to be drawn from elsewhere.

The wood waste and residues that are developed from the manufacture of plywood and lumber alone are not likely to yield sufficient volumes of wood chips to support the production of particleboard, fiberboard, or even the marketing of wood chips for exporting. For this reason the use of noncommercial timber for the production of wood chips could play an important role in the utilization of mill residues (Nelson 1960; Nelson and Wheeler 1963). And some of the raw material required for producing fiberboard products might be derived from other agricultural byproducts, such as the bagasse fibers from the sugar cane that is processed in the islands (Wright and Phelps 1967).

An optimum mix of raw materials, products, and markets is necessary for an efficient wood products industry. To provide a perspective of the manufacturing opportunities that may exist for expanding the Hawaii wood products industry, two models were developed *(tables 2, 3)*. They illustrate, in an arbitrary fashion, one variety of wood products that might be produced from an assumed annual supply of 20 million board feet of Hawaii sawtimber.

Plantation forests do not offer a great volume of timber. But they do offer a volume sufficient to develop a variety of small- to medium-sized manu-

The trim and edging waste from lumber and plywood production in combination with some volumes of noncommercial timber may supply much of the raw materials required for fiberboard or particleboard production in Hawaii.

Table 2–*Manufacturing opportunities: a market model for Hawaii timber products*

Timber products	Manufacturing requirements				Totals	
	Sawmills	Peeler plants	Slicer plants	Wood chip plants	Annual timber requirements	Est. unit value[1]
	Thousand bd. ft.					*Dollars*
Imported logs and flitches	2,000	1,900	100	–	4,000	134.00
Hawaii-grown sawtimber	12,000	7,850	150	–	20,000	35.00
	Cords					*Dollars*
Non-commercial Hawaii timber	–	–	–	10,000	10,000	10.00

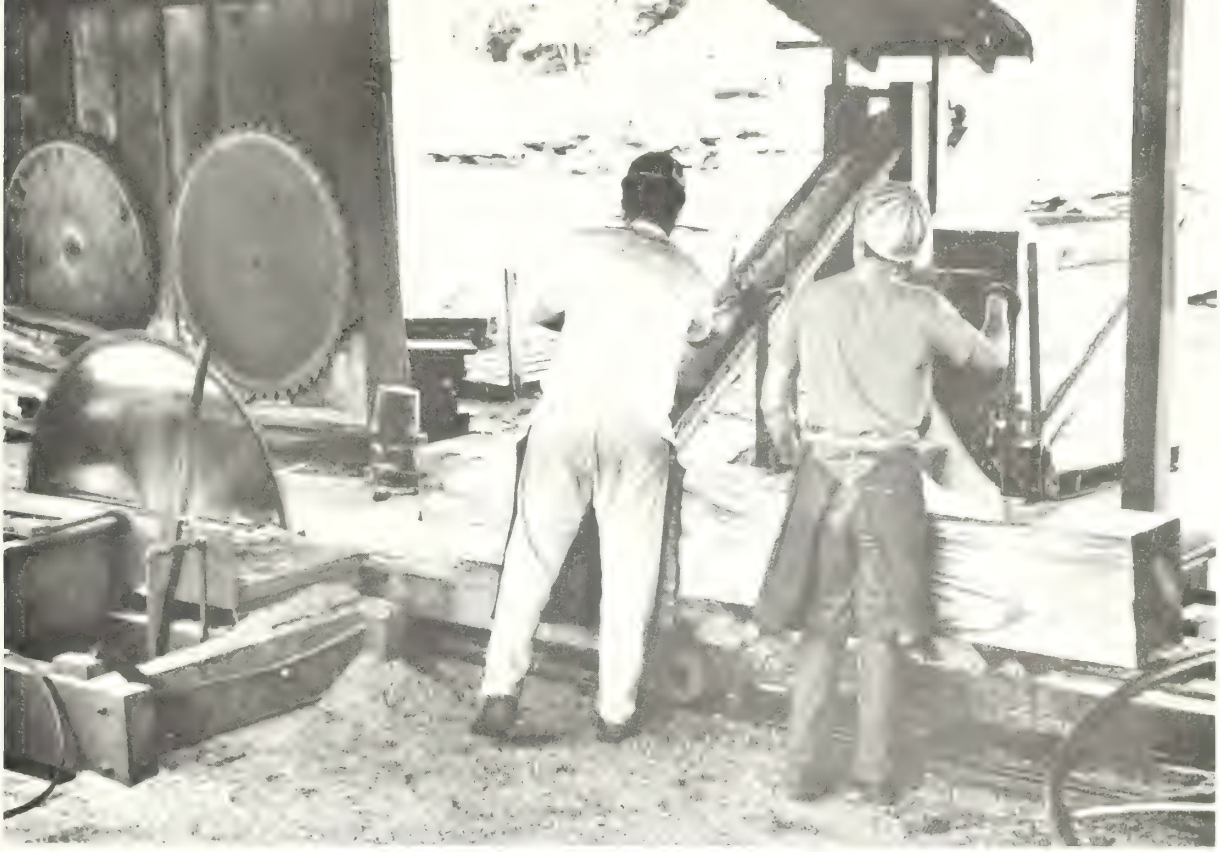
[1]Unit values are the estimated net values to the sellers at 1967 prices.

Table 3–*Manufacturing opportunities: a market model for Hawaii wood products*

Wood products	Manufacturers' requirements															Totals	
	Sawmills	Peeler plants	Slicer plants	Wood chip plants	Dry kiln, remanufacturing plants	Planing mills	Plywood plants (not decor.)	Decorative plywood plants	Particle board plant	Flooring manufacturers	Edge glue manufacturers	Moulding plants	Furn. parts & cut stock manufacturers	Wood pallet manufacturers	Miscellaneous user markets	Est. annual requirements	Est. unit values[1]
Logs and cordwood																*Units*	*Dollars*
Sawmill logs . . . . . MBF	14,000			[2]1,540												14,000	49.00
Peeler logs . . . . . MBF		9,750		[2]3,410												9,750	54.30
Decorated veneer logs . MBF			250	[2] 25												250	75.00
Cordwood . . . . . CDS				10,000												10,000	10.00
Primary products:																	
Rough green lumber . . . . . MBF					14,000											14,000	90.00
Rotary veneer . . . . MSF-3/16 in.							46,800									46,800	16.40
Sliced veneer . SF-3/32 in.								2,500								2,500	16.70
Wood chips STN-8/12" MC									30,000							30,000	7.40
Major commodity products																	
Rough dry lumber . . . . . MBF						10,000				250		750	1,000		2,000	14,000	149.00
Dressed worked lumber . . . . . MBF										750	2,000	250	2,000	4,000	1,000	10,000	170.00
Plywood, not decorated . . MSM-3/8 in.								2,500							20,900	23,400	58.00
Decorated plywood . . MSM-3/8 in.															3,750	3,750	120.00
Particle-board MSM-3/4 in															17,000	17,000	35.25
Special products:																	
Flooring . . . . . MBF															1,000	1,000	173.40
End and/or edge glued lumber . . . . . MBF															2,000	2,000	170.80
Mouldings . . . . . MLF															8,000	8,000	28.55
Furniture parts, cut stock . . . . . MBF															3,000	3,000	500.00
Wood pallets . . . . . No.															125,000	125,000	4.00

[1]Unit values are the estimated net values to the sellers, 1967 prices.

[2]Waste recovery



This "little American mill" has been in almost continuous operation at one place or another in Hawaii since 1942. Koa is being manufactured into products that will probably be used by the craftwood and furniture industries.

facturing operations that might later be supported with additional yields of timber from other commercial forests. The small and adaptable sawmill has been predominant in Hawaii.[4] These small units have been flexible enough to meet the demands of local markets, and to match their production capabilities with the supplies of local timber. The inability to reach beyond the local markets has, however, often restricted needed growth and created a basic instability in their operations.

Industrial Expansion

Hawaii's forest resources will support an expansion of wood products manufacturing. Lumber manufacture from Hawaii-grown timber has ranged between 0.5 and 6 million board feet per year since the mid-1950's (LeBarron 1964; Wick 1968). But forest inventory data have shown that Hawaii can support a wood products industry with a much larger volume of timber than is now being used (Nelson and Wheeler 1963). The island of Hawaii has about 600 million board feet of mature sawtimber *(table 1)*. This volume could support a cut of 18 to 20 million board feet per year for 30 years—before forest management can increase the amounts of timber that Hawaii's commercial forests can contribute in the future (Holt and Nelson 1959; Honda, Wong, and Nelson 1967; Nelson and Honda 1966).

To expand wood products manufacture in Hawaii, manufacturers must first be able to establish competence to meet both their production and marketing objectives on the basis of current opportunities (Malcolm 1960). To do this with the greatest possible advantage, a manufacturer must evaluate distant markets and possibly compete with other established species and sources of wood products. Product acceptance under these conditions will de-

[4] Otteson, Conner Piper. *A study of lumber distribution in Hawaii*. 1961. (Unpublished thesis on file at graduate school, University of Hawaii, Honolulu, Hawaii, 1961).

Lumber often deteriorates into unmerchantable condition when the small sawmill operator cannot find local markets for the items that result from specified order cuttings.

pend greatly on whether his products can substitute in use as well as in quality and price.

Present technologies and methods do exist for the manufacture of several species of Hawaii's present timber supply into products that demand fine quality and good appearance.[5] The challenge to each producer is to produce at a profit. To do this, markets must be developed, and products must be manufactured in qualities demanded by these markets. Therefore, manufacturers should know the locations, requirements, and systems of distribution to a variety of different wood product markets.

Framework for Marketing

Supply and Demand

The total demand for wood products in the United States is many times the manufacturing potential to be found in the State of Hawaii. National consumption of lumber since 1950 has run between 35 and 41 billion board feet. Plywood consumption has steadily increased since 1950 from 2,673 million square feet (⅜-inch basis) to 12,610 million square feet (⅜-inch basis) in 1966 (Hair and Ulrich 1967). Consumption patterns represent many specific relationships of supply and demand, and reflect the general conditions of the competitive marketing opportunities that are available to all producers. While the total amount of wood products that might ever be produced from Hawaii forests are, at best, a drop-in-the-bucket when compared to the volumes of national consumption, specific opportunities for the development of a wood products industry in Hawaii can be expected to be influenced significantly by these total consumption patterns. Changes in any market area become important because of the ripple effect they may have upon markets that are physically and economically accessible to the Hawaii manufacturer.

In 1967, Hawaii's markets consumed about 121 million board feet of lumber and 26 million square feet of plywood (⅜-inch basis)—less than one-fourth of 1 percent of the 1966 national levels of consumption *(table 4)*.

The total consumption of lumber by U.S. markets in 1966 increased by 4 billion board feet from a level of 36 billion board feet in 1960. Softwood plywood consumption increased 4.8 billion square

[5] Boone 1965a, 1966; Skolmen 1963, 1968b, 1968c; Skolmen and Smith 1962; Smith 1960. See also: Putnam, J. A., and Branch, W. C. *A report on the feasibility of quality hardwood production on Honaunau Forest and in Hawaii*. 1965. (Unpublished report on file at Southern Forest Experiment Station, Stoneville, Mississippi); and Skolmen, R. G.; Johnson, R. C.; and Budres, G. V. *Processing robusta eucalyptus from logs into furniture*. 1968. (Unpublished report on file at Institute of Pacific Islands Forestry, Honolulu, Hawaii.)

Table 4 – *Apparent consumption–production, import, export–of lumber, plywood, and veneer in Hawaii, by products, 1967*

Products		Produced in Hawaii	Shipped from		Exports	Apparent consumption
			U.S. Mainland	Other countries		
			LUMBER			
Hardwoods	MBF	3,925	(1)	[2]1,513	(1)	5,498
Softwoods:[3]						
WWPA Member Mills	MBF	0	11,343	(1)	(1)	11,343
CRA Member Mills	MBF	0	8,101	(1)	(1)	8,101
Others	MBF	0	[4]95,578	[4]818	[4]32	96,364
Total		3,925	[5]115,022	[5]2,391	[5]32	121,306
			PLYWOOD AND VENEER			
Hardwood	MSM[6]	0	(1)	[2]2,579	(1)	2,579
Softwood	MSM	0	[7]16,194	0	(1)	16,194
Others	MSM	0	[4] 5,772	[4]1,299	[4]107	6,964
Total		0	[5]21,966	[5]3,673	[5]107	25,532

[1]Not available.

[2]U.S. Department of Commerce Report AQ246.

[3]WWPA = Western Wood Products Association; CRA = California Redwood Association.

[4]Volumes of totals not otherwise accounted for.

[5]U.S. Army Corps of Engineers. Short tons converted on this basis:
Foreign imports of lumber 3,500# = 1,000 BFM
Domestic imports of lumber 2,500# = 1,000 BFM
Domestic imports of timbers, post & pilings 3,200# = 1,000 BFM
Domestic imports of plywood 1,125# = 1,000 SM 3/8 inch.

[6]Estimated 3/8 inch rough equivalent.

[7]American Plywood Association.

feet (⅜-inch basis), and hardwood 2.3 billion square feet from 1960 levels of consumption. An estimated 14.3 billion square feet (1-inch basis) of all wood products were used solely in the manufacturing industries in 1960. Nearly 90 percent of all hardwood products produced and imported in 1960 were consumed by the manufacturing industries. Wood from other countries represented 142 million board feet, or 1 percent of the lumber used in manufacturing in 1960. This volume included 47 million board feet of mahogany, 47 million board feet of Philippine hardwoods, and 48 million board feet of other woods that may be similar to the products an expanded Hawaii forest products industry could produce (Gill 1965).

At one time the United States exported significant quantities of hardwoods to overseas markets. Since the late 1940's, however, hardwood plywood imports have increased to 60 percent of domestic consumption, and hardwood lumber imports have increased to 5 percent of the total United States market. The major reasons for these shifts are the growing shortage of mainland supplies of high quality hardwood timber and the rapid expansion of many hardwood-using markets (Siegel and Row 1965).

Ability of domestic manufacturers to meet hardwood demands has been complicated by the drop in total hardwood production from 9.8 billion board feet per year in 1947–48 to 8 billion feet in 1961–62. Since then prices for all grades of hardwoods have risen steadily. And sizable markets that look to distant sources for high quality wood and cheaper supplies of lower quality hardwood material have been created.[6]

Transportation

Transportation often determines the relevancy of a market. Both the time and cost of transporting wood products influence the ability of a manufacturer to compete within different markets. In mar-

[6] See footnote 2.

keting commodity products to local markets, the Hawaii manufacturer has an advantage in transportation costs. Wood products manufacturers in Hilo, for example, have a $23.95/MBFM and a 30- to 90-day time advantage over mainland waterborne competition. Honolulu is the only port served by regular schedules of shipping between the mainland and Hawaii. It is possible to contract special services with Hawaii and mainland barge services—usually at significantly lower rates for large volumes than those allowed by the tariffs of carriers operating on regular schedules of service.

In the future, air freight may play an important role in the marketing of high value wood products. The special advantages of air freight are speed, frequency of schedules, relatively small cargoes that can be efficiently handled, and frequency of services provided to many points not regularly serviced by other means of transportation. In recent years, air freight has carried such wood products as doors, mouldings, carvings, ornaments, and furniture parts. Almost 26,000 pounds of furniture parts were imported to the United States from Europe by air freight in 1967. The average value of these shipments of wood furniture parts was slightly over $1.00 per pound to the sellers. This is an average value of at least $2,000 per thousand board feet (U.S. Bureau of the Census 1967). These markets are only a few hours' distance from any of the Hawaiian Islands by air freight.

Existing systems of distribution provide an important opportunity for marketing Hawaii wood products. Most wood products manufacturing is done far from the major markets and the focal points of the many services performed by market intermediaries. Collectively, market intermediaries create a distribution-market where products are bought to satisfy the requirements of a variety of final users. These firms perform many of the necessary functions of marketing, and exist mainly because they can perform these functions as specialists more cheaply than most manufacturers or consumers. For these reasons distributors may often provide the extensive effort that is necessary to gain the best advantages of the many geographic and user markets that may be available.

Structure of Markets

Four main groups of participants make up the structure of wood product markets: consumers, industry, producers, and market intermediaries. Important elements in the consumer markets are the do-it-yourselfers, tourists, home and furniture buyers. In the industrial markets are home builders, construction contractors, and furniture and cabinet manufacturers. Producers include primary manufacturers of lumber, veneer, plywood, and particleboard; processing operations include surfacing, profiling, and gluing operations. Intermediaries bring these many elements of the markets together.

In the distribution of wood products the more predominate types of intermediaries may be classified into six basic types of firms—in Hawaii as well as on the mainland:

1. *Retail-Only Firms:* Sell to do-it-yourselfers, small builders, and small manufacturing firms. The average volume of sale in board feet is usually small. This firm normally sells paint, nails, floor coverings, tools, and other hardware items as well as wood products.
2. *Wholesale-Retail Firms:* Sell to do-it-yourselfers and small manufacturing firms as a retailer. It also sells at wholesale prices larger volumes of materials to contractors, builders, and medium size firms. This type of firm is also able to sell some volumes of materials to the retail-only firm because it can buy large volumes of products often at better prices, and because of the inventory function it often performs for many low volume specialty items.
3. *Wholesale-Only Firms:* Sell to retail lumber yards, large contractors, builders, cabinet shops, and furniture manufacturers. It does not solicit do-it-yourselfer trade or small contractor trade.
4. *Mill Representatives:* Work on a salary, commission, or some combination basis as an employee of a mill. They are usually called sales representatives and may sell to brokers and wholesalers as well as to retail and industrial firms.
5. *Brokers:* Usually represent more than one producing mill. They usually work on a commission basis, but may often buy and sell for their own account as an office wholesaler. They traditionally sell only to retail-only and industrial type firms.
6. *Import-Export Firms:* Usually function as brokers or mill representatives for a foreign mill or foreign trading company or as customers' agents or representatives.

Hawaii and Pacific seaport markets provide a basis for the expansion of wood products manufacturing in the State. Many cities of Hawaii form

Table 5—*Hardwood products imported to Honolulu, Hawaii, and to selected United States Pacific Coast seaports, 1967*

Wood products	United States Customs districts of unloading . . .						Sub-total	Total United States	Unit price[1]
	Honolulu, Hawaii	San Diego	Los Angeles	San Francisco	Portland	Seattle			
Primary lumber products:									
Rough Philippine mahogany & lauan . . MBF	1,177	105	3,794	1,851	2,342	9,267	18,536	31,863	$152.18
Other rough hardwood lumber . . MBF	59	8	677	1,558	1,452	563	4,317	20,219	$149.18
Dressed and profiled products:									
Philippine mahogany and lauan . . . . . MBF	244	7	328	1,166	458	426	2,629	7,025	$193.45
Other hardwood lumber . . . . . MBF			113	206	29	1,020	1,368	5,634	$168.07
Specialty manufacturing:									
Strip & plank hardwood flooring . . . . . MBF	53	–	8	26	1	–	88	991	$173.36
Hardwood flg. except strip & plank . . . . . MBF	31		28		1		60	1,963	$458.39
End-glued lumber products . . . . . MBF	9		118	3		76	206	806	$170.82
Wood furniture parts . . . . . Dollars	20,896	81,982	605,264	143,910	129,178	53,574	1,034,804	5,660,079	
Standard hardwood mouldings . . . . . MLF	365		1,908	9,514	10,578	14,990	37,355	2,622,581	$ 28.55
Broom, mop & other wood handles . . . Number	22,222	69,450	588,000	–	45,000	4,604,686	5,329,358	11,267,776	6.8¢
Plywood - unfinished decorative:									
Birch thicker than 5/32 in. . . . . SFT	448,928	735,523	15,606,675	4,619,308	15,014,634	2,832,077	39,257,145	150,864,558	12.2¢
Philippine mahogany thicker than 5/32 in. . . . . SFT	1,602,055	70,086,312	252,241,347	8,465,833	266,045,942	5,848,582	604,290,071	1,147,245,185	4.4¢
Plywood finished decorative:									
Birch thicker than 5/32 in. . . . . SFT	35,360	142,778	189,302	971,517	386,455	825,654	2,551,066	26,915,157	11.7¢
Philippine mahogany thicker than 5/32 in. . . . . SFT	429,360	9,057,054	11,692,219	11,704,707	13,943,670	4,162,420	50,989,430	395,042,345	5.3¢
Plywood finished & unfinished decorative:									
With walnut face . . . SFT	6,848	24,000	2,560,180	304,772	2,440,003	842,140	6,177,943	13,142,033	16.35¢
With miscellaneous hardwood faces . . . SFT	56,352	973,392	19,902,943	4,194,256	5,892,630	78,776	31,098,349	104,456,882	7.76¢
Consumer products:									
Folding wooden chairs . . . . . Dollars	1,702	118,556	97,429	20,772	325	2,748	241,532	1,555,266	
Wooden chairs not folding . . . . . Dollars	111,514	10,621	3,361,698	676,315	83,652	124,589	4,368,389	15,213,310	
Wood furniture . . . Dollars	189,163	328,514	2,575,384	1,596,005	89,774	196,173	4,975,013	26,786,063	
Decorative mouldings, carvings & orn. . . . Dollars	24,080	48,852	325,829	282,637	1,165	39,838	722,401	3,999,940	
Wooden forks & spoons except mahogany. . Dollars	28,966	624	17,924	13,763	628	1,335	63,240	574,626	
Specialty wood carvings . . . . . Dollars	128,163	9,158	272,925	187,995	8,476	21,219	627,936	2,936,705	
Misc'l wooden household items . . Dollars	547,032	292,962	719,987	1,111,772	453,357	70,989	3,196,099	15,292,636	
Combined market value . . . Dollars	1,747,596	4,480,551	23,109,101	7,293,405	16,528,112	4,751,096	57,910,547	186,790,525	

Source: U. S. Bureau of the Census. January–December 1967. United States imports of merchandise for consumption. Reports 1A 245 and IQ 245 (unpublished).

[1]The unit price values shown are average market values realized by the sellers of the products listed where import duties, freight charges, marine insurance and other amounts paid to bring these products to their points of final use would have to be added to indicate their market value in the market place.

the primary markets for Hawaii wood products. Such cities as San Diego, Los Angeles, San Francisco, Portland, and Seattle form secondary markets because of their relative accessibility. Within these mainland markets are many marketing alternatives. Each market uses large volumes of wood products of all descriptions.

As for accessibility, the tree fern production of Hawaii provides a good example of how an industry has successfully marketed its products in both Hawaii and the mainland. In little more than 15 years this industry has expanded from about 100,000 cubic feet of tree fern products manufactured in 1958 to an estimated 144,000 cubic feet in 1967. The development of both Hawaii and mainland markets has been essential for this growth (Nelson and Hornibrook 1962).

Many hardwood products are being imported to Hawaii, and other U.S. Pacific seaport markets *(table 5)*. Products manufactured from Philippine mahogany and lauan represent the largest volumes of lumber and plywood products being imported, but other species are also represented. They include walnut and apitong. To the extent that the present timber supply in Hawaii can be used to satisfy current market requirements, and to the extent that timber can be grown for future markets imports represent important marketing opportunities for Hawaii-grown wood products. To establish competitive marketing positions manufacturers will have to promote sales in specific product-markets. To do so, the traditional and technical standards of the market, and the preferences and cost values of specific users must be satisfied. To accomplish these objectives, two important kinds of effort are especially important which may be described as "competitive marketing" and "market development" activities.

The objective of competitive marketing is to capture a share of an existing market, with products just-like-everybody-elses. Competitive prices may be sufficient to "competitively" enter an established market as a newcomer; but wood product manufacturers can introduce slight differentiations to obtain competitive advantages. For example, products may be differentiated by producing large assortments of lengths if the product is flooring, or by offering preferred textures or colors if the product is paneling. However, where extreme product differences exist, unfamiliar species are being introduced, or new sources of supply are being made available, market development efforts will be required. Wood samples, technical data, and other promotional efforts will be a "must." New product buyers will have to be provided the information needed to evaluate effectively new products and to arrive at a purchasing decision. The Hawaii Wood Products Association and other forest industry associations can contribute to these promotional efforts.

Markets in Hawaii

Demands in Hawaii now exceed the present supplies of Hawaii-grown wood products. Because true demand is difficult to measure, a proxy for it is often used called "apparent consumption." In Hawaii, the apparent consumption of wood products in 1967 supported demands for about 121 million board feet of lumber and 26 million square feet (3/8-inch basis) of plywood. Hawaii's forests contributed less than 4 million board feet of lumber to this total. The balance came from imports. The mainland is the largest supplier of wood products. Canada supplied almost the entire volume of softwoods imported to Hawaii from other countries. Nearly $1.9 million of hardwood products were imported to the State in 1967—more than 70 percent of it coming from Taiwan, Japan, and the Philippines *(table 5)* (Harpole 1969).

Plywood imports to Hawaii have been increasing rapidly since 1954, whereas the imports of lumber remained almost constant until 1963 *(table 6)*. These patterns are similar to those of plywood and lumber consumption for the mainland. Although the demands for all wood products have expanded, the demands for plywood products have increased their proportionate share of the total demand. Plywood is used today almost exclusively for roof and wall sheathing, subflooring, and concrete form work in residential home construction. The trend of plywood to displace lumber, however, has slowed in recent years and could give way to hardboard, particleboard, and other types of panel products (U.S. Forest Service 1965).

A significant relationship is the one between population and wood products consumption. When

population projections are coupled with changes in the per capita demand, as reflected in the 1950 to 1961 period, Frazier (1965) estimated that the consumption of lumber in Hawaii by the year 2000 will be between 100 and 123 million board feet for all species. Military demands could possibly double this amount, but the assumption of this estimate for the year 2000 does not reflect the level of military demand for wood products. This condition is illustrated in part by the significant volume of wood product imports and consumption in Hawaii since 1963 that is related to increased military activity in the Pacific. A corresponding estimate of plywood demand for the year 2000, which also excludes the possibilities of high military-demand levels, is 40 million square feet (3/8-inch basis). This will represent an increase of about three times over the 1960–61 level of plywood consumption (Frazier 1965) *(table 7)*.

Table 6 – *Lumber and plywood imported to Hawaii, 1954-1967*

Year	Lumber imports[1]	Plywood imports[2]
	MBF	*MSM 3/8 inch*
1954	74,804	1,959
1955	76,850	731
1956	94,918	1,428
1957	82,432	1,796
1958	86,495	3,680
1959	95,995	22,480
1960	95,597	15,963
1961	68,918	9,793
1962	68,864	10,881
1963	117,227	([3])
1964	149,817	([3])
1965	138,731	10,548
1966	140,264	16,588
1967	117,413	25,639

[1]Territory (State) of Hawaii, Board of Harbor Commissioners, Annual Reports, June 30, 1954-June 30, 1962. U.S. Army Corps of Engineers, Pacific Regional Statistical Office, 1965 through 1967.

[2]U.S. Army, Corps of Engineers, Pacific Regional Statistical Office. Report prepared for U.S.F.S. Jan. 17, 1964; converted from short tons to square feet, 3/8-inch basis. (1 short ton = 1,777.8 square feet, 3/8-inch basis.) 1961 through 1967 include foreign import data from Bureau of Census, U.S.D.C., U.S. Imports of merchandise for consumption. Dist. No. 32, Annual Summaries.

[3]Not available.

Distribution Markets

Wholesale-retail dealers provide the largest distribution market in Hawaii. For the most part the Hawaii retail firm bypasses the broker and wholesaler in buying lumber, plywood, and veneer. Instead, he buys directly from the producer. The estimated gross volume of lumber handled in the Hawaii wood products market in 1962 was a little more than 81 million board feet.[7] Mill representatives, brokers and wholesalers play a minor role in the distribution of lumber products from sawmills; most purchases are made "directly" at retail and wholesale-retail lumber yards *(fig. 1)*. Some volumes are purchased from other firms of a like category that may account for specialty items handled by one firm but not by others.

Lumber sales in Hawaii by distribution intermediaries are clearly dominated by the wholesale-retail and retail lumber firms. In 1962, they accounted

[7] Frazier, G. D., Mackenzie, K. D., and Weber, J. H. *The market potential for Hawaii timber.* 1964. *The market potential for Hawaii timber resources. A record of marketing research planning, results, and evaluations,* 1964. (Unpublished reports on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Berkeley, Calif.)

Table 7–*Estimated consumption of lumber and plywood in Hawaii, 1950 to year 2000*

Years	Average population	Lumber consumption		Plywood consumption	
		Per capita consumption	Annual avg. consumption	Per capita consumption	Annual avg. consumption
		BF	*MMBF*	*SM(3/8 in.)*	*MMSM (3/8 in.)*
1950-52	470,000	170	80	([1])	([1])
1956-57	525,000	170	89	3.0	1.6
1960-61	600,000	150	90	21.6	12.9
2000[2]	1,000,000	111	111	40.0	40.0

[1]Not available.

[2]Assumes a continued growth in population, and the same trends and proportions of wood product demands between military and civilian sectors as reflected by the 1950 to 1961 period.

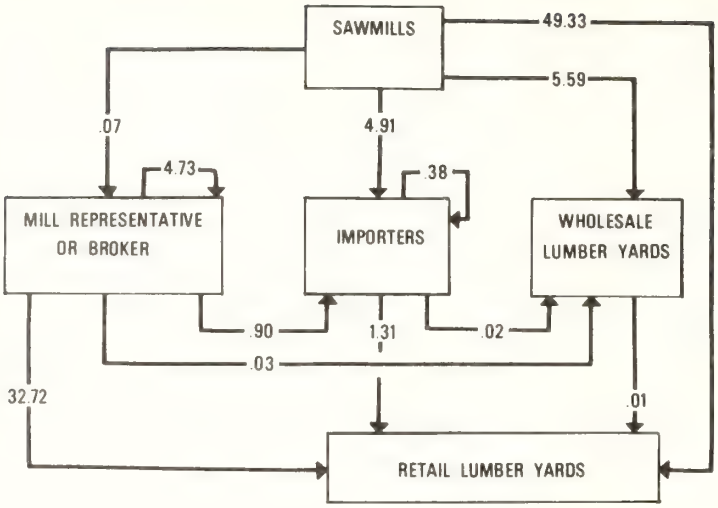


Figure 1 — *Nearly half the total volume of lumber traded in the Hawaii wood products market in 1962 was purchased directly by retail lumber yards from sawmills. Figures are in percents.*

for more than 85 percent of such sales *(table 8)*. The single largest user-customers were the industrial and construction markets.

The flow of plywood and veneer through the market differs from that of lumber. The importer plays a more important role in the distribution of plywood and veneer—accounting for more than 15 percent of the total purchases in Hawaii from mills. The total volume of plywood and veneer that moved through the Hawaii markets in 1962 was about 18.3 million equivalent board feet (¾-inch basis). As in lumber sales, the largest markets for plywood and veneer are industrial and construction users *(table 9)*. Figure 2 illustrates the distribution of the plywood and veneer purchases between the different classes of market intermediaries. Again, the retail and wholesale-retail type firm is found to purchase plywood products principally from producing mills. And only an estimated 17 percent of these purchases flow through other market intermediaries.

Construction Markets

Construction markets are the largest users of wood products in Hawaii. As elsewhere in the United States, more than two-thirds of all the lumber, plywood, and many wood specialty products are consumed by these markets. The most important segments of the markets are residential homes, garden apartments, and light commercial types of construction. Wood framing, roof decking, plywood subfloors, flooring, exterior siding, and interior paneling are the main wood products used.

Several distinctive architectural features tend to characterize the single-family home and styles used in low-density apartment buildings, churches,

Table 8—*Percent of lumber sales reported by the Hawaii wood products market, 1962*

Seller	Sold to . . .						Total
	Wholesale-retail or retail only	Wholesaler	Furniture	Cabinet shops	Industrial and contractor	Do-it-yourselfer	
Importer	0.93	0.65	0.43	0.13	3.73	0.04	5.91
Mill representative or broker	.00	.00	.00	.91	8.15	.00	9.06
Wholesaler	.05	.18	.55	.09	4.07	.45	5.39
Retailer	5.58	1.76	2.28	2.28	65.63	2.11	79.64
Total	6.56	2.59	3.26	3.41	81.58	2.60	100.00

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

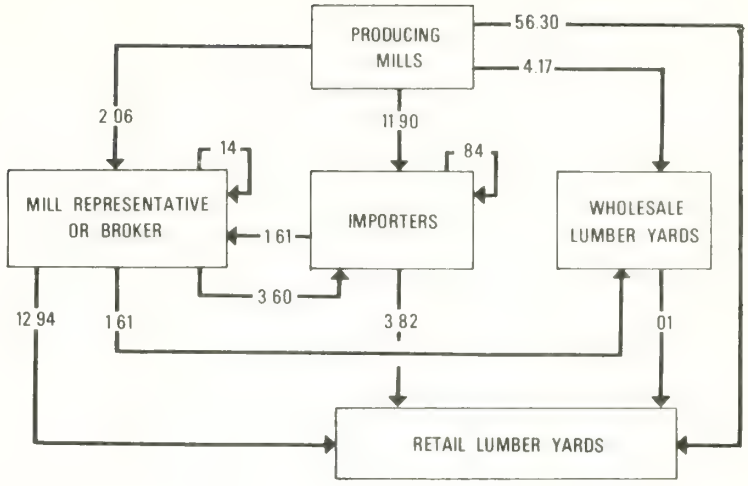


Figure 2 — *More than half the total volume of plywood and veneer traded in the Hawaii wood products market in 1962 was purchased directly by retail lumber yards from plywood mills. Figures are in percents.*

Ohia and several eucalyptus species are especially well suited for the manufacture of attractive, long-wearing flooring.

Table 9—*Percent of plywood and veneer sales as reported by the Hawaii wood products market, 1962*

Seller	Sold to . . .						Total
	Wholesale-retail or retail only	Wholesaler	Furniture	Cabinet shops	Industrial and contractor	Do-it-yourselfer	
Importer	7.40	3.07	2.02	0.44	3.80	0.04	16.77
Mill representative or broker	.00	.00	.00	.33	2.97	.00	3.30
Wholesaler	.37	.79	.52	.56	2.60	.10	4.94
Retailer	5.66	1.94	2.44	2.45	60.48	2.02	74.99
Total	13.43	5.80	4.98	3.78	69.85	2.16	100.00

schools, and recreational facilities in Hawaii. On the mainland, single-family home designs are normally double walled construction with gabled roofs. This type of building uses large volumes of wood products. In Hawaii, single-family residential construction typically has exterior walls of concrete block or wood siding as a single wall system. Interior walls in these "single wall" houses are usually wooden partitions of 1-inch panel thickness (Smith 1960). Electrical lines, consequently, are installed beneath mouldings or in attic spaces. Other modifications accommodate the other services that double-wall construction usually encloses.

Since about 1965, the use of double-wall construction in Hawaii has increased. This trend may continue. Also, in the Honolulu area the Federal Housing Administration reports that about 85 percent of all new homes are being built on concrete slab floor-foundation systems. In the Hilo area, however, nearly 95 percent of the homes are of crawl space designs. Homes there are normally built on a custom basis without the benefit of the "tract" methods that are used in the more rapidly growing Honolulu area (Zinnikas and Boone 1967a).

Residential construction in Hawaii can be compared in many ways to that found in Florida, where resistance to rot and termite infestation is of primary concern, and heating requirements are relatively less important. For these reasons, there should be opportunities in the Hawaii construction markets for the development of many types of products derived from 4/4-inch hardwood materials with which mainland woods cannot so effectively compete. Examples include: decorative paneling for interior wall partitions, accent walls, shelving, cabinetry, exposed ceiling panels, plank flooring, thresholds, door jambs, and window sills and mouldings. Hardwoods should not be excluded from possible competition in uses for framing, sheathing, and sidings. But softwoods are much better established for these uses and they are often inherently more adaptable and cheaper than for other uses where hardwoods excel.

A forecast of single-family home construction in Hawaii for the 1965 to 1970 period suggested that about 4,650 units would be built each year (Federal Housing Administration 1967a; Zinnikas and Boone 1967b). If a 3-bedroom home with a total area of 1,050 square feet were taken as a model Hawaii home, construction markets could annually require about 6.5 million square feet of exterior siding, 4.5 million square feet of interior wall panel, 4 million square feet of flooring, 5 million square feet of roof decking or ceiling panel, 6 million board feet of ceiling beams, and additional volumes of materials for mouldings, door jambs, cabinets, shelving and other products *(table 10)*. Other volumes of wood products will be used in the repair and remodeling of existing units, as well as in the construction of motels, restaurants, and other light commercial structures.

Furniture Markets

Furniture manufacturers are important users of quality hardwoods. Because furniture manufacturing is closely related to the growth in population, it is not surprising that Hawaii's furniture industry

Table 10—*Estimates of annual average requirements of construction materials for new single-family homes in Hawaii, by end use, 1965-1970*

Market area	Single family units[1]	Exterior siding	Interior wall partitions	Flooring or floor systems	Exposed ceiling panels	Exposed ceiling beams	Door jamb sets	Kitchen cabinets	Shelving	Misc'l mdl'gs
	No.	*SM*	*SM*	*SM*	*SM*	*BFM*	*BFM*	*BFM*	*SM*	*LF*
Honolulu	3,500	4,886,000	3,500,000	3,111,500	3,675,000	4,536,000	259,000	1,281,000	385,000	3,248,000
Hawaii[2]	500	698,000	500,000	444,500	525,000	648,000	37,000	183,000	55,000	464,000
Kauai	200	279,200	200,000	177,800	210,000	259,200	14,800	73,200	22,000	185,600
Maui	450	628,200	450,000	400,050	472,500	583,200	33,300	164,700	49,500	417,600
Combined total	4,650	6,491,400	4,650,000	4,133,850	4,882,500	6,026,400	344,100	1,701,900	511,500	4,315,200
Est. amount per house[3]		1,396	1,000	889	1,050	1,296	74	366	110	928

[1]Estimated by Federal Housing Administration.

[2]Island of Hawaii.

[3]Based on a single-family residential home model with 1,050 sq. ft. floor area.

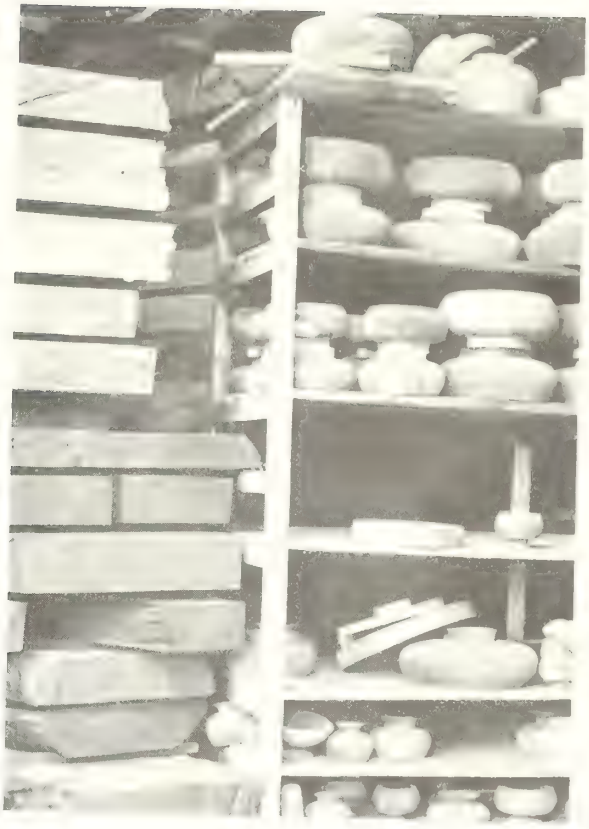


Table top blanks, top, *of monkey-pod, koa, mango, and other Hawaii hardwood species are often sold to do-it-yourselfers for final finishing. Careful drying is necessary to obtain a good craftwood product,* right. *Monkey-pod and koa,* bottom, *also are among the favorite species found in Hawaii that are used in manufacturing furniture and novelty products.*

has expanded steadily since 1950. Initially most of the manufacturing plants were small custom type manufacturers who employed relatively few people and catered to a small clientele of furniture wholesalers and retailers in Hawaii. In many cases, the larger wholesalers and retailers manufactured a part of the furniture they sold. As a few retail firms grew in size they also developed into large manufacturers of furniture.[8]

By far the largest volume of furniture manufacturing in Hawaii is on Oahu. In 1962, the basic furniture manufacturing industry consisted of 24 firms. They generally produce finished furniture. There were no furniture parts producers in Hawaii in 1962, and there are none today.

The Hawaii furniture industry is geared principally to the use of Philippine mahogany lumber and plywood. The trend is towards the use of other species of hardwood as well. And there is evidence of a shift from native koa to other species, such as walnut, alder, and other hardwoods from both mainland and foreign sources. This shift could be of major importance to the Hawaii wood products industry if a dependable supply of well manufactured and seasoned hardwood lumber can be produced *(tables 11, 12)*.

No data are available on the volume of wood furniture parts being shipped into Hawaii from the mainland, but the amounts being imported from other countries are small. In 1967 the total value of the foreign imports of furniture parts was only $20,896. All but $355 of this amount was imported from Japan. Most Hawaii firms purchase some furniture parts of both softwoods and hardwoods from the mainland (U.S. Bureau of the Census 1967). Turned furniture legs, drawer sides, and drawer bottoms are bought in the largest volume. Assembled furniture is not normally shipped because the bulk to weight ratio is unfavorable.

Lumber imported to the Hawaii furniture industry usually comes directly from mills in Japan and the Philippine Islands. The furniture manufacturer orders his lumber directly from the mill, or a mill representative. But usually only large-volume furniture manufacturers buy directly from mills *(fig. 3; table 13)*. Unlike the market channels for lumber, nearly 90 percent of the plywood is usually purchased about evenly from local suppliers and from importers *(table 14)*.

Continued population growth in Hawaii will sustain further growth in Hawaii's furniture manufacturing industry. And the development of new styles will tend to place Hawaii timber products, especially the more desirable introduced species, in a more favorable market position.

[8] See footnote 7.

Table 11—*Consumption of lumber and plywood in the furniture industry in Hawaii, based upon the functional organization of the industry, 1962*

Functional category	Firms	Wood products consumption	
		Lumber	Plywood[1]
	No.	*Thousand board feet*	
Finished furniture manufacturing	9.21	1,166	185
Unfinished furniture	.52	55	3
Furniture parts, unassembled	.00	–	–
Furniture parts, assembled	.10	3	1
Other furniture manufacturing	4.00	100	6
Total	13.83	1,324	195

[1]Plywood figures are in board feed equivalents, where it is assumed that 1 square foot of ¾-inch plywood equals 1 board foot lumber scale.

Table 12—*Specific composition of the hardwood wood products inputs to the Hawaii furniture industry, 1962*

Species	Percent of total consumption	
	Lumber	Plywood
Philippine mahogany	65	98
Koa	22	2
Alder	11	–
Walnut	2	–
Total	100	100

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest and Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

Transportation Markets

The economy of the State of Hawaii is based upon transportation. The transportation industry provides important markets for many under-utilized grades of lumber. A limited survey suggests that Hawaii's transportation industry uses 8 million board feet of lumber annually—most of it

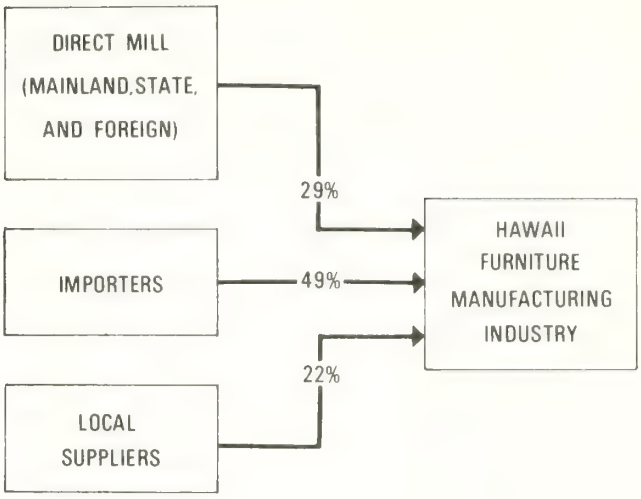


Figure 3 — *Imports made up nearly half of the lumber purchased by the Hawaii furniture manufacturing industry in 1962. The remainder came from local suppliers and mills. Figures are in percents.*

Table 13–*Source of lumber for Hawaii furniture industry, by type of furniture, 1962*

Source	Type of furniture					Total
	Finished (8.21)[1]	Unfinished (.52)[1]	Parts, unassembled (0)[1]	Parts, assembled (.10)[1]	Misc. (4)[1]	(13.83)[1]
Direct mill	29.14	0.23	–	–	0.01	29.38
Importer	38.51	3.55	–	–	6.80	48.85
Broker/mill rep.	–	–	–	–	–	–
Wholesale lbr. yard	1.59	.03	–	.27	.15	1.99
Wholesale-retail lbr. dealer	18.80	.38	–	–	.60	19.78
Total	88.03	4.18	–	.27	7.56	100.00

[1]Number of responses by furniture manufacturers to survey.

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

Table 14–*Source of plywood and veneer for Hawaii furniture industry by type of furniture manufactured, 1962*

Source	Type of furniture					Total
	Finished (8.16)[1]	Unfinished (.36)[1]	Parts, unassembled (0)[1]	Parts, assembled (.10)[1]	Misc. (1.25)[1]	(9.83)[1]
Direct mill	8.63	0.03	–	–	0.14	8.80
Importer	43.56	.35	–	–	–	43.91
Broker/mill rep.	–	–	–	–	–	–
Wholesale lbr. yard	2.73	–	–	.29	–	3.02
Wholesale-retail lbr.	40.38	1.04	–	–	2.85	44.27
Total	95.30	1.42	–	.29	2.99	100.00

[1]Number of responses by furniture manufacturers to survey.

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

in the manufacture of 300,000 pallets each year (Boone 1965b; Zinnikas 1966).

Between 5 and 6 million board feet of lumber are used annually in the shipment of pineapple alone (Zinnikas 1966). The transportation industry normally uses "disposable" pallets, which typically are made of the lowest grades of softwood and hardwood lumber. In the past these pallets have been shipped fully assembled from the mainland and then loaded with pineapple and shipped out again. In addition to disposable pallets, a considerable volume of lumber is used in reusable pallets for overseas and inter-island shipments. It has been conservatively estimated that between 2 to 3 million board feet of both softwood and hardwood lumber is used annually in the manufacture of reusable pallets. Most shipping companies maintain their own pallet manufacturing and repair facilities, and a considerable number of pallets are fabricated by the larger lumber supply houses. One company in Hawaii estimates that it uses nearly 1 million board feet of lumber annually in the manufacture of reusable pallets in addition to its consumption of lower grades of lumber. The total volume of lumber used in both types of pallets can be an important market for many low-value and under-utilized grades of lumber that an expanded wood products industry can create.

Military Markets

The military markets offer a variety of wood product demands, chiefly in housing and military support uses. A large volume of the demands for wood products derive from housing requirements and are realized through the usual channels of supply that service Hawaii contractors and subcontractors. Wood products used in the transporting of military personnel and equipment, and in establishing and maintaining bases of operation are purchased through two regional suboffices of the U.S. Defense Construction Supply Center (Zinnikas 1966).

Most of the 113 million board feet of lumber shipped to military markets in the Pacific Basin in 1963 were softwoods, with only 141,000 board feet of hardwood species *(table 15)*. Slightly more than 3 million board feet of this volume were used in Hawaii. In combination with other volumes of plywood, mouldings, ties, piles and other products, the amount of lumber used by the military services provide another important market in Hawaii for an expanded wood products industry.

Pallet manufacturing in Hawaii uses about 8 million board feet of softwood and hardwood lumber each year. Norfolk-Island-pine shown is being used to make warehouse pallets.

Markets in the United States Mainland

Pacific Coast Markets

Most of the mainland markets may be considered inaccessible to Hawaii-produced wood products because of transportation cost or time. The regular schedules of ships linking Honolulu to the Pacific Coast of the mainland, however, do offer a marketing opportunity. Of the markets available, Los Angeles is the largest consumer of lumber, plywood, and veneer products. And it shows many of the distribution patterns that are to be found within the other mainland markets.

Table 15—*The military market for lumber and wood products in the Pacific Basin, 1963*[1]

Item	Hawaii	West Coast	Other Pacific	Total
	Thousand board feet			
Lumber:				
Softwood	3,299	30,271	76,935	110,505
Hardwood	141	174	2,202	2,517
	Thousand sq. ft. surface measure			
Plywood and veneer:				
Softwood	688	6,973	6,265	13,926
Hardwood	–	105	127	232
	Linear feet			
Molding	123,137	42,939	6,000	172,076
Batten strip	7,000	–	–	7,000
	Each			
Ties	600	129,187	9,500	139,287
Crossarms	123	290	10,892	11,305
Piles	899	401	1,320	2,620
Line construction poles	189	663	7,229	8,081
Wood poles	70	120	11,155	11,345
Doors	–	174	3,753	3,927

[1]Source: Regional Procurement Suboffices, U. S. Defense Construction Supply Center, Atlanta, Georgia, and Portland, Oregon.

Los Angeles Market

In 1962, the highly complex Los Angeles market traded about 4.9 billion board feet of lumber and 1.7 billion equivalent board feet (¾-inch basis) of plywood and veneer. Some of the firms there sell only to consumers; others only to retail, industrial, or other intermediary firms. But some intermediaries sell to both consumers and other lumber firms, or to other combinations including industrials.[9]

About 4 billion board feet of lumber entered the Los Angeles distribution markets directly from producing sawmills in 1962. The total amount of lumber traded, however, was about 4.9 billion board feet. Therefore, roughly 20 percent of the total amount of lumber traded (about 1 billion board feet) filtered through two or more levels of market intermediaries before reaching the retail level where it is normally distributed to final users, or ultimate consumers *(fig. 4)*.

An important characteristic of the Los Angeles lumber markets is the dependence of both industrial buyers and consumers upon different types of sellers. For instance, the most important sources of lumber for finished furniture manufacturers are mill

[9] See footnote 7.

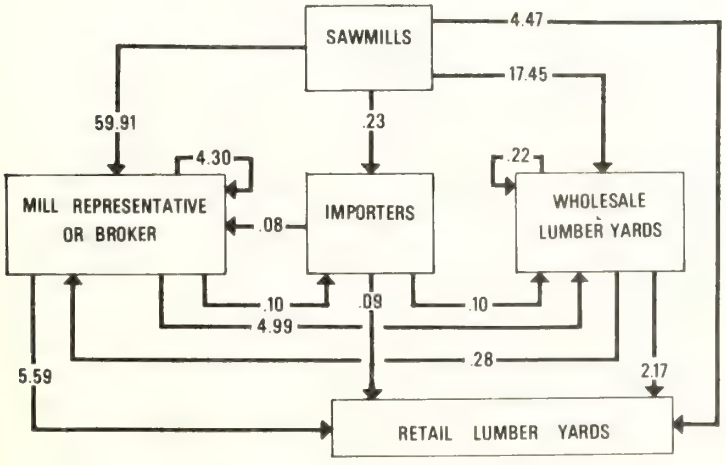


Figure 4 — *Nearly 60 percent of the total volume of lumber purchased in the Los Angeles wood products market in 1962 was taken for trading by mill representatives and brokers. Figures are in percents.*

representatives and brokers. The most important sources of lumber for cabinet shops are wholesalers. Industrialists and contractors rely most heavily on retail lumber yards, but also buy significant quantities of lumber from wholesalers. The sales of lumber to do-it-yourselfers (1.8 percent) by brokers and mill representatives are the result of composite type firms operating partly as a broker or mill representative, and partly as retail outlets *(table 16)*.

In comparing the distribution of plywood and veneer products with the distribution of lumber, two distinct market structures are apparent. This is not too surprising because of differences in methods of production, and because of the relative newness of plywood and veneer distribution *(table 17; fig. 5)*. About 82 percent of the lumber is purchased directly from producing mills; 90 percent of the plywood and veneer is purchased this way. Similarly a large proportion of the direct mill purchases of plywood and veneer goes through a mill representative or broker. On the other hand, wholesalers buy only an estimated 7 percent of the plywood, but nearly 23 percent of the total volume of lumber distributed.

The Los Angeles furniture market offers important marketing opportunities for fine hardwoods. Among the many consumers of wood products in the industrial markets of the mainland, the furniture industry is one of the largest which uses sizable volumes of hardwood products. And it provides

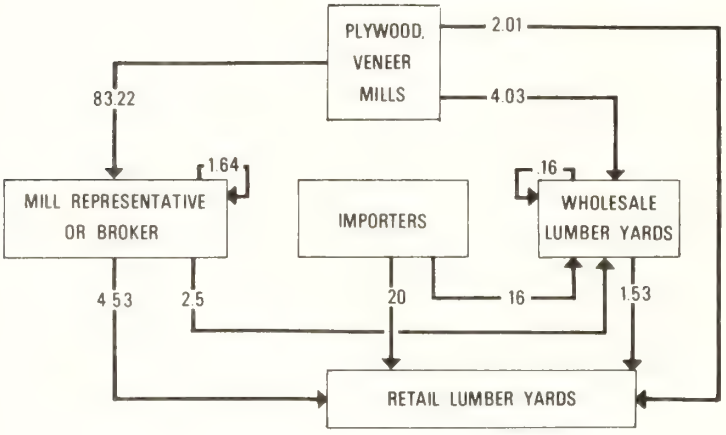


Figure 5 — *About 84 percent of the total volume of plywood and veneer purchased in the Los Angeles wood products market in 1962 was taken for trading by mill representatives and brokers. Figures are in percents.*

Table 16—*Percent of the lumber sales reported by the Los Angeles wood products market, by type of buyer, 1962*

Buyer	Lumber sold by . . .				Total
	Importer	Mill representative or broker	Wholesaler	Wholesale-retail or retail only	
Wholesale-retail or retail only	0.15	42.29	9.72	0.37	52.53
Wholesaler	.04	9.61	3.09	.08	12.82
Finished furniture	.02	.62	.31	.02	.97
Unfinished furniture	0	.15	.50	.01	.66
Framemakers	0	.15	.35	.01	.51
Cut and dimension stock	0	.08	.17	0	.25
Cabinet shops	.16	.96	2.20	.09	3.41
Industrials, contractors	0	3.19	6.49	13.46	23.14
Do-it-yourselfer	0	1.82	1.46	2.43	5.71
Total	.37	58.87	24.29	16.47	100.00

Source: Frazier. G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

Table 17–*Percent of plywood and veneer sales reported by the Los Angeles lumber market, by type of buyer, 1962*

Buyer	Sold by . . .			Total
	Mill representative or broker	Wholesaler	Wholesale-retail or retail only	
Wholesale-retail or retail only (includes direct mill)	0	1.68	0.02	1.70
Wholesaler (includes direct mill)	80.0	1.53	0	81.53
Finished furniture	4.44	.01	.03	4.48
Unfinished furniture	0	0	.02	.02
Framemakers	0	0	.02	.02
Cut and dimension stock	0	0	0	0
Cabinet shops	.49	.01	.09	.59
Industrials, contractors	0	3.63	5.23	8.86
Do-it-yourselfer	0	.01	2.79	2.80
Total	84.93	6.87	8.20	100.00

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

markets for some of the highest valued wood products sold as well as many of the lower grades of hardwoods and softwoods. Los Angeles is not only the country's largest furniture manufacturing center, but probably has the greatest concentration of manufacturing plants in the smallest area of any region. Because of its proximity to Hawaii, the Los Angeles market can be a major outlet for the better qualities of Hawaii-grown hardwood products (Frazier, Weber, and Mackenzie 1964a, 1964b; Weber, Frazier, and Mackenzie 1965).

Furniture production is characteristically market-located rather than being located close to sources of raw materials. Plants locate close to their final markets to provide custom manufacturing and to minimize the cost of carrying finished-product inventories. This tendency to locate plants close to buyers is shown in the ranking of the 20 top states in number of furniture plants and their corresponding rank in population *(table 18)*. California leads in number of plants and in population.

Of the 84.6 million board feet of lumber reported as consumed by the Los Angeles furniture manufacturing industry in 1962, most of it went into finished furniture. This estimate of consumption, however, was based on a restrictive functional definition of "the market" *(table 19)*. A "total" volume of lumber consumption for all direct and indirect phases of furniture manufacturing in 1962 was estimated to have been closer to 130 million board feet. The volume of lumber consumed in Los Angeles is greater than in other furniture manufac-

Table 18–*States with the most furniture manufacturing establishments (1963), by rank in number of establishments and rank in estimated population (1967)*

State	No. of establishments[1]	Rank in no. of establishments	Rank in population[2]
California	1,504	1	1
New York	1,434	2	2
Pennsylvania	570	3	3
Illinois	531	4	4
North Carolina	518	5	11
Florida	387	6	9
Texas	382	7	5
Massachusetts	376	8	10
Michigan	385	9	7
New Jersey	353	10	8
Ohio	337	11	6
Indiana	272	12	12
Tennessee	231	13	17
Missouri	182	14	13
Wisconsin	166	15	16
Georgia	166	16	15
Washington	145	17	23
Virginia	137	18	14
Minnesota	123	19	20
Connecticut	118	20	24

[1]U. S. Department of Commerce. 1963 census of manufacturers: location of manufacturing plants, part 3, Washington, D.C. Total of plants in following S.I.C. code classifications: 2511, 2512, 2514, 2515, 2519, 2521, 2522, 2531, 2541, 2542, 2599. Classification 2591, Venetian blinds and shades, is not included in these totals as it does not refer to the furniture industry in the context of this report; that is, as a major market for lumber.

[2]U. S. Department of Commerce.

Table 19–*Lumber consumption reported by the Los Angeles furniture manufacturing industry, 1962*

Functional classification	Total lumber consumption	Lumber consumption per firm
	—— *Thousand bd. ft.*——	
Finished furniture and "other" not elsewhere classified	55,071	389
Unfinished furniture	3,687	295
Furniture parts mfgr., unassembled	20,731	1,728
Furniture parts mfgr., assembled	5,101	291
Total	84,590	

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

turing centers. But the percentage of the output from the Los Angeles industry in metal and plastic furniture is higher than that from other centers. This furniture either does not use wood or uses a low quality lumber for framing. In particular, the volume of furniture manufactured there that uses high-quality hardwoods, as in tables, chairs, and case goods, is not as great as in the North Carolina and Michigan furniture manufacturing industries.[10] In Los Angeles, a manufacturer of tables typically may buy legs from a local wood turner, cut-to-size plastic laminated tops from a second local manufacturer, the extension assembly from an eastern plant, and cut-to-size lumber from an Oregon mill. In essence, many Los Angeles furniture factories more nearly resemble assembly plants than furniture plants in other markets that process logs and rough lumber into finished furniture.

Finished furniture and "other furniture" manufacturers purchase most of their lumber from mill representatives or brokers, and report the highest percentages of purchases direct from sawmills. Unfinished furniture manufacturers depend heavily upon wholesalers for their lumber purchases. Furniture parts manufacturers obtain most of their lumber from wholesale lumber yards. Assembled furniture parts manufacturers obtain their lumber in about equal proportions from sawmills and wholesalers *(table 20)*. Importers supplied about 45 percent of the 15,489,000 equivalent board feet of plywood and veneer purchased in 1962. These figures suggest that wholesalers are less important as sources of plywood and veneer than of lumber. Mill representatives or brokers and direct mill purchases are less important sources of plywood and veneer than of lumber *(table 21)*.

Manufacturers of unassembled parts account for about 6 percent of the plywood and veneer consumption, and about 25 percent of lumber consumption. Manufacturers of unfinished furniture account for about 18 percent of total plywood and veneer consumption and only about 4 percent of the lumber. The percentage consumptions for finished furniture manufacturers or "other not elsewhere classified" and assembled furniture-parts manufacturers are about the same *(table 22)*. These figures reflect what we know about furniture man-

[10] See footnote 7.

Table 20–*Percent of lumber purchases reported by the Los Angeles furniture manufacturing industries, by type of buyer, 1962*

Buyer	Purchased from . . .					Total
	Direct mill	Importer	Mill representatives or brokers	Wholesaler	Wholesale-retail or retail only	
Finished furniture manufacturer and other furn. mfgr. not elsewhere classified	14.09	0.23	28.66	21.07	1.07	65.12
Unfinished furniture manufacturer	.00	.00	.01	4.34	.01	4.36
Furniture parts mfgr., unassembled	3.14	.02	3.98	17.36	.00	24.50
Furniture parts mfgr., assembled	2.62	.13	.70	2.41	.16	6.02
Total	19.85	.38	33.35	45.18	1.24	100.00

Table 21—*Reported plywood-veneer consumption by the Los Angeles furniture manufacturing industries, 1962*

Functional classification	Total plywood-veneer consumption	Plywood-veneer consumption per firm
	Thousand equivalent bd. ft.	
Finished furniture and "other" not elsewhere classified	10,763	74
Unfinished furniture	2,860	212
Furniture parts mfgr., unassembled	980	77
Furniture parts mfgr., assembled	886	51
Total	15,489	–

Source: Frazier, G. D.; Mackenzie, K. D.; and Weber, J. H. *The market potential for Hawaii timber resources . . . a record of marketing research planning, results, and evaluations.* 1964. (Unpublished rep. on file, Pacific SW. Forest & Range Exp. Sta., U. S. Forest Serv., Berkeley, Calif.)

ufacturing methods: plywood and veneer is used more in the final assembly than in the manufacture of parts or subassemblies.

This information is important. There is evidently much more demand for plywood and veneer in finished and unfinished furniture than in furniture parts. An investigation of the reasons why more plywood and veneer are not used more in parts manufacturing could possibly lead to their increased use.

Studies of the Los Angeles furniture market suggest that many of the existing hardwood species in Hawaii have an excellent market potential. The even grain and medium-to-dark tones of koa and robusta carry a definite prestige. Preference for these wood characteristics is expected to continue. Woods that will finish in natural color to these darker tones will carry the highest premiums. While the best qualities of home furnishings have always been wood, there has been a degree of vacillation in preferences among wood, metal, plastics, and imitations of wood finishes in lower quality articles. For these reasons, the Los Angeles furniture industry appears to hold the most important potential for the higher qualities of hardwood lumber, plywood, and veneer that can be produced from Hawaii timber. Transforming this market potential into an effective demand for Hawaii woods, however, will depend in large measure upon the ability of Hawaii wood products manufacturers to process native grown timber into wood products that will be suitable for remanufacture into furniture parts and assemblies—and at competitive prices with similar products. [7, 11]

[11] Roberts, E. V. *Forest survey, general, Hawaii.* 1957. (Unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Berkeley, Calif.)

Table 22—*Plywood-veneer purchases reported by the Los Angeles furniture manufacturing industries, by type of buyer, 1962*

Buyer	Purchased from . . .					Total
	Direct Mill	Importer	Mill representatives or brokers	Wholesaler	Wholesale-retail or retail only	
	Percent					
Finished furniture mfgr.[1]	7.93	27.16	15.15	18.43	.82	69.49
Unfinished furn. mfgr.	1.34	9.12	5.78	2.19	.03	18.46
Furniture parts mfgr., unassembled	.00	6.08	.05	.19	.00	6.32
Furniture parts mfgr., assembled	2.64	2.65	.00	.43	.01	5.73
Total	11.91	45.01	20.98	21.24	.86	100.00

[1]Includes other furniture manufacturer (wood user) not elsewhere classified.

Summary and Conclusions

To evaluate the resources and marketing opportunities for Hawaii wood products, the Pacific Southwest Forest and Range Experiment Station joined with the Hawaii Division of Forestry in a series of studies. A forest survey was started in 1958, and marketing research in 1963.

The following conclusions can be drawn on the basis of studies completed to date:

Hawaii's forests provide a sufficient base from which to develop a diversified and expanded wood products manufacturing industry.

As shown by both resource and market studies, wood products can be produced from the present inventories of Hawaii timber to the competitive qualities demanded by wood products markets. The introduction of plywood production, and the expansion of lumber production in Hawaii are presently technically and logistically feasible. Fiberboard or particleboard production could also be started. Mill residues may not provide a sufficient supply of wood chips, but additional volumes of raw materials could be developed from the noncommercial stands of Hawaii's present timber supply, and from the State's other agricultural resources.

To support a new and diversified wood products manufacturing industry, at least 722 million board feet of mature sawlog-size timber in the commercial forest of Hawaii along with other large volumes of noncommercial timber are available. For the future, if only 100,000 acres of the more than 1 million acres of commercial forest in Hawaii are properly managed, it is reasonable to expect that a sufficient volume of timber will be supplied in 30 to 40 years to support the production of 50 to 100 million equivalent board feet of wood products production each year. In contrast, the total volume of lumber production from Hawaii-grown timber in 1967 reached a level of about 6 million board feet—well below even the estimated 18 to 20 million board feet of production that could be temporarily supported by the plantation forests of Hawaii until more extensive programs of timber production could become effective.

The future value and expansion of wood products manufacture in Hawaii will depend upon tree planting and stand improvement programs.

Although the present timber supplies are sufficient for the introduction of a diversified wood products industry, the future value of Hawaii-grown timber can be assured only through an expansion of intensive timber management programs. Many varieties of hardwood and softwood species can be grown in Hawaii. And because of the prodigious growth rates that may be obtained in many sites in Hawaii, the future economic contributions of forests there will depend largely on how well current tree planting and stand improvement programs are made to match the requirements of future markets and manufacturers.

Local and mainland markets could support an expanded Hawaii wood products industry.

Hawaii markets annually consume close to 121 million board feet of lumber, and 26 million square feet (⅜-inch basis) of plywood. Hawaii's "potential" wood products industry does not exist today, and the sawtimber that can be available in 25 to 30 years has not been planted or started to grow. For these reasons the Hawaii wood products industry can direct its development toward the future wood product demands of local and mainland markets.

The per capita consumption of lumber in Hawaii is expected to decline in the future, but plywood per capita consumption is expected to increase. By the year 2000—under normal peacetime conditions—the State of Hawaii is expected to consume annually close to 111 million board feet of lumber and 40 million surface feet of plywood (⅜-inch basis). Additionally, there will be many opportunities to develop products for specific mainland markets. Many of the markets that an expanded Hawaii wood products industry may solicit will consume much larger volumes than they now do.

An expansion of the Hawaii wood products industry will depend upon the ability of Hawaii manufacturers to compete with other wood product manufacturers.

To become established and to expand, the Hawaii wood products manufacturing industry must operate realistically on the basis of available resources, markets, and manufacturing technologies. Product acceptance in all markets will depend upon the ability of these products to substitute in use as well as in quality and price for other products. The Hawaii wood products manufacturer has a significant advantage in accessibility to the Hawaii "home" markets. But to provide the greatest possible economic advantage some volumes of production will have to seek geographically distant markets in competition with other established species and sources of wood products.

The Pacific Coast markets of the mainland hold

many well defined marketing opportunities for hardwoods. One of the most important is in the Los Angeles furniture manufacturing market, which has traditionally been willing to pay the highest prices for consistent supplies of high quality hardwood products. Existing sources of supply and distribution systems now supply this and the many other user markets of the mainland. If the Hawaii producer is to compete successfully, he will have to make products of the qualities demanded and sell these products in markets that will provide the highest return.

The success of an expanded wood products industry could well rest on the type of timber management program now being developed. An expanded industry would provide manufacturers to make more furniture parts, industrial cut stock, and end-and-edge type of lumber products. Each of these manufacturing activities has its own special technical and qualitative requirements. And each may have its own unique marketing problems. An expanded timber management program would need to reflect these requirements.

This report has brought together what is known about the demand for Hawaii wood products, the probable consumption pattern, the extent and location of forest resources, and the market and its structure. Armed with this information, the manufacturer is ready to decide on investment opportunities and on what should be done next.

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Appendix

Table 23 – *Area of commercial forest land by ownership classes, Hawaii, 1961*

Ownership	Acreage
Public:	
Federal (military)	8,600
State	487,300
County and Municipal	400
Total	496,300
Private:	
Farmer-owned	365,900
Miscellaneous private	226,700
Total	592,600
All ownerships	1,088,900

Source: Nelson and Wheeler (1963).

Table 24–*Forest lands in the State of Hawaii*

Island	Commercial forest	Unproductive forest	Productive reserved forest	Nonforest area suited for trees
	Thousands of acres			
Hawaii	709.0	343.9	80.7	239.0
Maui	120.4	141.8	1.4	10.6
Molokai	23.6	59.3	.0	5.7
Lanai	2.1	26.1	.0	2.3
Oahu	97.1	110.2	3.3	18.0
Kauai	136.7	86.3	.0	14.1
Kahoolawe	.0	11.7	.0	.0
Niihau	.0	28.0	.0	.0
Total	1,088.9	807.3	85.4	289.7

Table 25 – *Volume of growing stock and sawtimber, in planted sawtimber stands, by species, island of Hawaii, 1965*

Species	Growing stock	Sawtimber
	M cu. ft.	*M bd. ft.*[1]
Australian redcedar	23	88
Blackbutt eucalyptus	33	175
Brushbox	297	1,270
Deane eucalyptus	30	90
Eucalyptus spp.	1,802	7,287
Gray ironbark eucalyptus	18	96
Jhalna	98	224
Kinogum eucalyptus	286	1,282
Koa	3	14
Lemon eucalyptus	142	627
Maiden-gum eucalyptus	67	249
Molucca albizzia	221	1,154
Nepal Alder	135	497
Norfolk-Island-pine	274	1,359
Ohia	132	394
Port-Orford-cedar	5	–
Redwood	20	94
Robusta eucalyptus	16,830	80,673
Saligna eucalyptus	2,415	13,895
Silk-oak	844	3,191
Sugi	619	1,181
Tallowwood eucalyptus	195	991
Tropical ash	464	1,331
Turpentine-tree	134	661
Western redcedar	20	20
Total	25,107	116,843

[1]International ¼-inch rule.

Table 26 – *Volume of growing stock and sawtimber in planted sawtimber stands, by species and stand acreage, island of Maui, 1967*

Species	Growing stock	Sawtimber
	M cu. ft.	*M bd. ft.*[1]
Robusta eucalyptus	13,439	72,730
Bangalay eucalyptus	284	1,460
Blackbutt eucalyptus	31	195
Gray ironbark eucalyptus	108	597
Kinogum eucalyptus	70	324
Red-ironbark eucalyptus	26	115
Other eucalypts[2]	1,588	6,678
Hardwoods[3]	449	1,488
Redwood	1,277	6,223
Norfolk-Island-pine[4]	533	2,934
Sugi	303	1,030
Other conifers[5]	138	473
Total	18,246	94,247

[1]International ¼-inch rule.

[2]Includes turpentine-tree and brushbox.

[3]Australian toon, camphor-tree, koa, mahogany, Molucca albizzia, silk-oak, teak, and tropical ash.

[4]Includes hoop pine.

[5]Cluster pine, jelecote pine, Monterey pine, Port-Orford-cedar, and western redcedar.

Table 27—*Volume of growing stock and sawtimber in planted sawtimber stands, by species, island of Kauai, 1965*

Species	Growing stock	Sawtimber
	M cu. ft.	*M bd. ft.*[1]
Blackbutt eucalyptus	39	213
Blackwood acacia	75	381
Brushbox	30	63
Eucalyptus spp.	209	935
Gray ironbark eucalyptus	82	246
Hoop pine	9	14
Kinogum eucalyptus	62	372
Koa	15	50
Lemon eucalyptus	87	418
West Indies mahogany	1	1
Molucca albizzia	905	5,130
Norfolk-Island-pine	318	1,538
Ohia	11	42
Red-ironbark eucalyptus	18	45
Redwood	42	233
Robusta eucalyptus	3,328	14,566
Saligna eucalyptus	267	1,651
Silk-oak	83	342
Sugi	83	390
Tallowwood eucalyptus	39	192
Tropical ash	10	32
Turpentine-tree	5	4
Total	5,718	26,858

[1]International ¼-inch rule.

Table 28—*Volume of growing stock, sawtimber, and cull trees in planted sawtimber stands, by species, island of Lanai, 1966*

Species	Growing stock	Sawtimber	Cull trees
	M cu. ft.	*M bd. ft.*[1]	*Cu. ft.*
Robusta eucalyptus	450	1,672	19,262
Blackbutt eucalyptus	105	243	970
Other eucalypts	71	235	3,827
Molucca albizzia[2]	99	525	–
Tropical ash	47	108	3,670
Turpentine-tree	13	38	234
Australian redcedar	17	57	1,426
Other hardwoods[3]			1,680
Norfolk-Island-pine	9	42	
Noncommercial species[4]	–		6,378
Total	811	2,920	37,447

[1]International ¼-inch rule.

[2]No Molucca albizzia stands were large enough to be cruised, but log volumes of similar measured stands on Kauai were used here.

[3]Includes silk-oak and koa.

[4]Includes Casuarina spp. and bluegum eucalyptus.

Table 29 – *Volume of sawtimber and growing stock in planted sawtimber stands, by species and ownership class,*[1] *island of Molokai, 1967*

Species	Growing stock	Sawtimber
	M cu. ft.	*M bd. ft.*[2]
Blackbutt eucalyptus	28	130
Eucalyptus spp.	272	880
Lemon-gum eucalyptus	2	7
Red-ironbark eucalyptus	15	58
Robusta eucalyptus	2,603	10,410
Saligna eucalyptus	182	853
Tallowwood eucalyptus	62	221
Norfolk-Island-pine	4	24
Sugi	8	17
Total	3,176	12,600

[1]Based on interpretation of locations on Tax-Key maps and topographic maps which are often inadequate for precise determinations. Therefore, for a given plantation stand, the ownership designation may be in error, although over-all ownership statistics are probably not greatly affected by this kind of error.

[2]International ¼-inch rule.

Table 30 – *Volume of growing stock and sawtimber in planted sawtimber stands, by stand-size class and species, island of Oahu, 1966*

Species	Growing stock	Sawtimber
	M cu. ft.	*M bd. ft.*[1]
Blackbutt eucalyptus	901	4,281
Bloodwood eucalyptus	5	27
Brushbox	590	1,635
Gray ironbark eucalyptus	360	1,058
Jhalna	13	29
Kinogrum eucalyptus	3	8
Koa	13	59
Lanceleaf gum-myrtle	6	26
Lemon-gum eucalyptus	258	1,179
Marri eucalyptus	70	367
Molucca albizzia	64	272
Monkey-pod	22	120
Norfolk-Island-pine[2]	543	2,502
Ohia	1	3
Other hardwoods[3]	124	459
Red-ironbark eucalyptus	7	26
Robusta eucalyptus	4,550	19,559
Saligna eucalyptus	1,749	9,359
Silk-oak	1,053	2,536
Tallowwood eucalyptus	22	101
Tropical ash	13	23
Turpentine-tree	67	235
Unidentified eucalypts	484	1,962
Total	10,918	45,826

[1]International ¼-inch rule.

[2]Mainly Norfolk-Island-pine, includes sugi and Australian kauri.

[3]Australian toon, camphor-tree, mango, West Indies mahogany.

Table 31—*Physical properties of robusta eucalyptus, ohia, and six woods commonly imported to Hawaii*[1]

Species	Moisture content	Specific[2] gravity	Weight[3] per cubic foot	Total shrinkage (green to oven-dry)		
				Radial	Tangential	Volumetric
	Percent		*Pounds*	*Percent*		
Robusta eucalyptus	88	0.60	70	6.1	10.7	
(Eucalyptus robusta)	12	.66	46	–	–	–
Ohia	67	.70	73	6.9	12.1	19.1
(Metrosideros collina)	12	.81	57	–	–	–
Apitong[4]	80	.58	65	6.0	11.7	19.1
(Dipterocarpus spp.)	12	.70	49	–	–	–
Maple, sugar	58	.56	56	4.9	9.5	14.9
(Acer saccharum)	12	.63	44	–	–	–
Oak, white	68	.60	62	5.3	9.0	15.8
(Quercus alba)	12	.68	48	–	–	–
Douglas-fir (coast type)	38	.45	39	5.0	7.8	11.8
(Pseudotsuga menziesii)	12	.48	34	–	–	–
Lauan, red[4]	65	.45	46	3.7	7.4	12.5
(Shorea negrosensis)	12	.49	34	–	–	–
Redwood (virgin)	112	.38	50	2.6	4.4	6.8
(Sequoia sempervirens)	12	.40	28	–	–	–

[1]Source: Youngs, R. L. *Physical, mechanical, and other properties of five Hawaiian woods.* U. S. Forest Serv. Forest Products Lab. Rep. 2191, 34 p. illus. 1960.

[2]Based on weight when overdry and volume at test.

[3]Based on combined weight of wood and moisture and volume at test.

[4]Source: Bellosillo, S. B., and Miciano, R. J. *Progress report on the survey of mechanical properties of Philippine woods.* The Lumberman (Philippines), p. 17-21, illus. Aug.-Sep. 1959.

Table 32—*Comparative shrinkage and strength ranking of some well-known woods and robusta eucalyptus*[1]

Rank	Volumetric shrinkage	Bending strength	Compressive strength	Stiffness	Hardness	Shock resistance
1.	Redwood (69)	ROBUSTA (120)	ROBUSTA (118)	Apitong (220)	Sugar maple (115)	Sugar maple (137)
2.	Red lauan (121)	Apitong (114)	Apitong (108)	ROBUSTA (203)	ROBUSTA (112)	White oak (127)
3.	Douglas-fir (122)	Sugar maple (114)	Sugar maple (104)	Douglas-fir (185)	White oak (108)	ROBUSTA (103)
4.	Sugar maple (147)	White oak (102)	Douglas-fir (104)	Sugar maple (178)	Apitong (88)	Apitong (99)
5.	White oak (153)	Douglas-fir (90)	Redwood (102)	Red lauan (162)	Red lauan (59)	Douglas-fir (86)
6.	ROBUSTA (168)	Red lauan (90)	White oak (97)	White oak (153)	Douglas-fir (58)	Red lauan (82)
7.	Apitong (186)	Redwood (82)	Red lauan (86)	Redwood (136)	Redwood (54)	Redwood (66)

[1]Based on comparative index numbers, shown in parantheses, calculated at the U. S. Forest Products Laboratory, Madison, Wis., by procedure outlined, U. S. Dep. Agr. Tech. Bull. 1958 (1930). Data on Philippine wood calculated from Bellosillo and Miciano—see sources in table 31.

Table 33 – *Lowest applicable container rates for water borne shipments between Honolulu, Hawaii, and the principal United States West Coast seaports, 1968*

Item	Westbound	Eastbound
Rough lumber	$ 33.50/M ft.	$ 1.00/cwt (N.O.S. lbr.)[1]
Dressed lumber	33.50/M ft.	1.00/cwt (N.O.S. lbr.)
Flooring	1.62/cwt	1.00/cwt (N.O.S. lbr.)
Mouldings	625.00/container[2]	1.00/cwt (N.O.S. lbr.)
Industrial cut stock	715.00/container	630.00/container
Furniture parts	715.00/container	630.00/container
Furniture	715.00/container	630.00/container
Veneer	1.64/cwt	1.32/cwt (N.O.S. lbr.)
Plywood	1.64/cwt	1.32/cwt (N.O.S. lbr.)
Prefinished plywood	1.64/cwt	1.32/cwt (N.O.S. lbr.)
Wood carvings	715.00/container	630.00/container
Fiberboard and chipboard	1.45/cwt	1.00/cwt (N.O.S. lbr.)
Wood chips and sawdust	500.00/container	1.00/cwt (N.O.S. lbr.)

Source: Matson Navigation Company, Freight tariffs Nos. 14-A and 15-A.

[1]Lumber not otherwise specified by tariff provisions.

[2]Maximum cargo weight of a "Matson Van container" is 46,200 lbs. with a cubic capacity of 1,427 cubic feet. Minimum weight requirements exist for all commodities.

Table 34 – *Lowest available rates in cents per 100 pounds for air freight shipments of wood products between Hawaii and selected mainland airports, 1968.*[1]

Hilo, Hawaii							
NA	Honolulu, Hawaii						
71	71	Los Angeles, Calif.					
NA	NA	14	Portland, Ore.				
75	75	9	15	San Diego, Calif.			
71	71	9	11	11	San Francisco, Calif.		
NA	NA	17	9	19	13	Seattle, Wash.	
93	93	25	28	25	29	28	Chicago, Ill.
102	102	37	36	37	39	36	New York, N.Y.

Source: United Air Lines, San Francisco, Calif.

[1]For shipments weighing less than 100 pounds.

Table 35 – *Lowest applicable water rates (including wharfages and Hawaii state tax) in dollars per MFBM for inter-island shipment of "Hawaiian grown" wood products*[1], *1968.*

Hilo			
9.55	Honolulu		
24.05	17.54	Kailua, Kona[2]	
16.07	8.65	24.05	Maui

Source: Young Brothers, Ltd., Honolulu, Hawaii

[1]For shipment of 250 MFBM or more for deck stowage, for products derived from Hawaii-grown timber only.

[2]Includes trucking from Kawaihae to Kailua.

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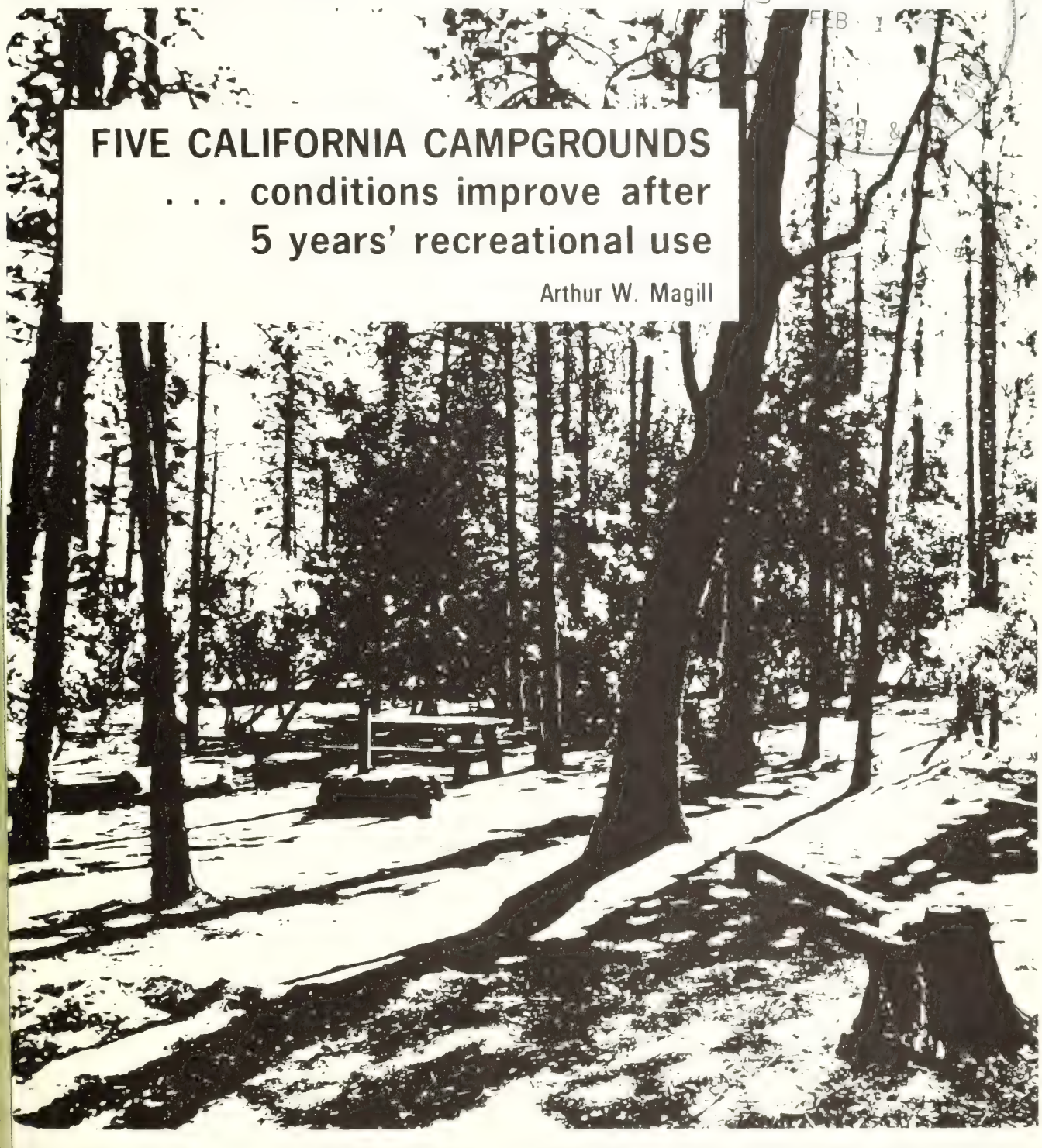
. . . conditions improve after 5 years' recreational use

Arthur W. Magill



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The Author

ARTHUR W. MAGILL is studying problems in the use of forest recreation areas, with headquarters in Berkeley. A native of Seattle, Washington, he is a 1957 forestry graduate of the University of Washington, and earned a master's degree in forestry at the University of California in 1963. He joined the Forest Service in 1957.

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Over a long period of time, the habitat of heavily used campgrounds appears to deteriorate. But how serious is this decline? Recent studies conclude that vegetation and soils of public campgrounds may be more resistant to visitor use than visual observations have suggested. In California, Hartesveldt (1963) found that trampling, root cutting for roads, and root covering by roads have not seriously impeded the growth of giant sequoia *(Sequoia gigantea).* In another California study, Magill and Twiss (1965) reported that heavily used campgrounds showed little changes in vegetation and soil surface over a 10-year period. In southeastern Michigan, Wagar (1964) determined that vegetation survival dropped as simulated recreational use increased, but deterioration did not accelerate. And in northwestern Pennsylvania, LaPage (1967) found that herbaceous ground cover was heavily depleted in the first year of use at a new campground located on a typical old field. Later, more resistant plants replaced those susceptible to trampling, but did not provide a ground cover equivalent to that existing before the site was used.

In 1961, the Pacific Southwest Forest and Range Experiment Station began a long-term study of changes in campground habitat. Part of the study included a comparison of plant growth on five campgrounds and at three sites not subject to recreational use. The study was not expected to explain all habitat changes. The relationship of changes on unused sites to those on campgrounds could only suggest whether recreational use might be responsible. And, information on climatic trends and administrative actions could suggest other reasons for habitat changes.

This paper reports the changes in habitat from 1961 to 1966 on the five campgrounds and on the neighboring sites not used for recreation. It evaluates the relative impact of factors responsible for the changes, interprets what these changes mean in terms of campground conditions, and suggests an approach for future research.

METHODS

The campgrounds and unused sites studied are on three widely separated National Forests in California *(fig. 1; table 1).* The campgrounds have been used for 16 to 30 years, with one exception. Barrier systems to control vehicular traffic were installed in 1960 and 1961. Recreational use at the five campgrounds rose steadily during the 5-year period.

Nested plots were either established along transect lines or uniformly distributed through the sites in a manner that would sample any obvious soil or vegetation differences *(fig. 2).* Plots were not extended into areas disturbed by roads, paths, parking spurs, power lines, pipe lines, or other recreation facilities.

Plots were measured in summer of 1961 and remeasured in 1966. The used and unused sites were compared, but because their soils and vegetation could not be shown to be related, true "controls" were not established. And because the major study areas were widely separated—Lake Almanor is 580 miles north of the Laguna Recreation Area—the differences in soils, vegetation, and climate prohibited any direct comparisons between campgrounds.

Horse Heaven, being a group campground, had to be sampled in a different way. A 150-foot radius semicircular area was subdivided into quarters to sample trees, and 15 nested plots were established *(fig. 3).* The five nested plots nearest the center had some overlap, but this proved of little significance

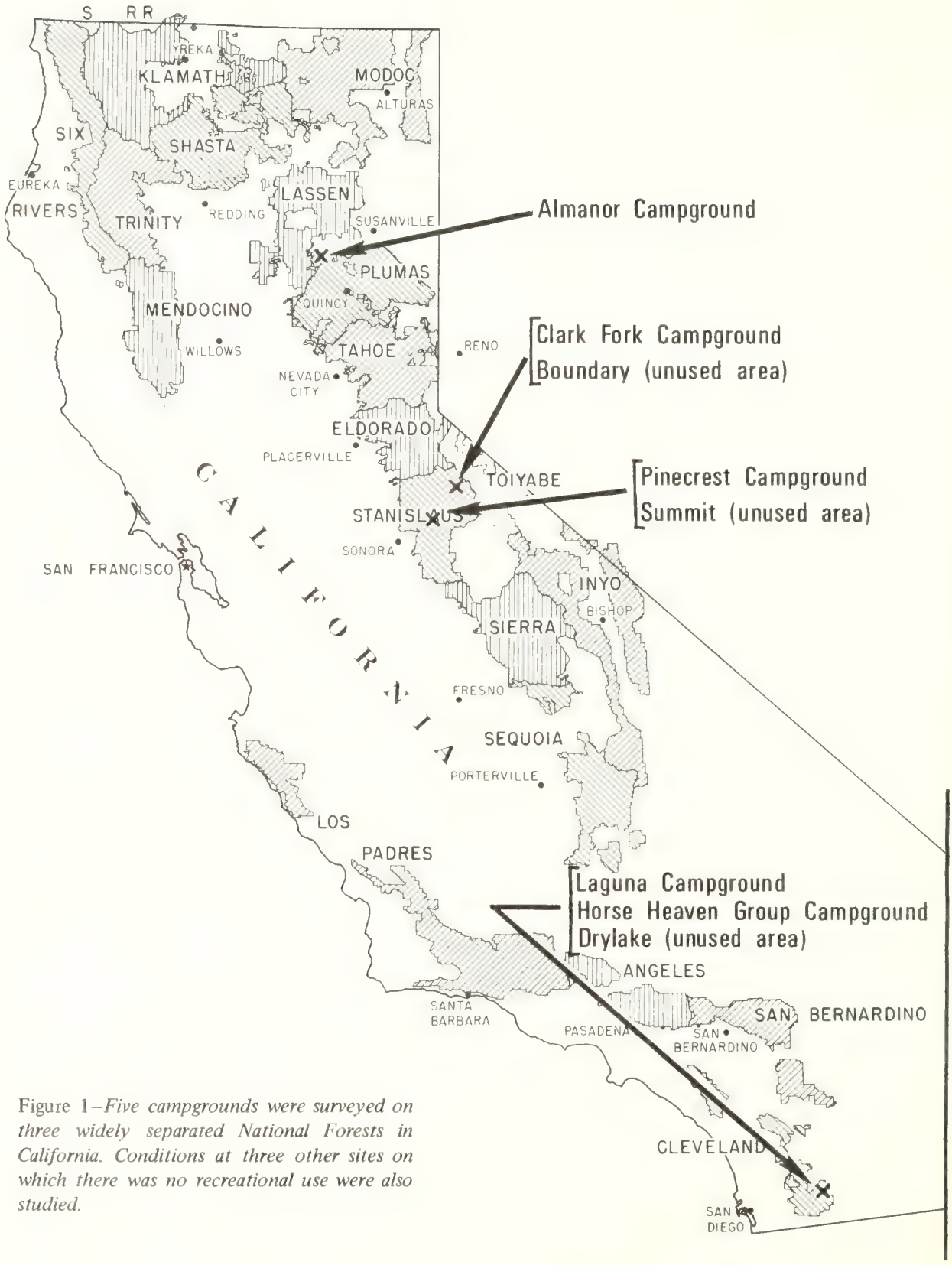

Figure 1—*Five campgrounds were surveyed on three widely separated National Forests in California. Conditions at three other sites on which there was no recreational use were also studied.*

Table 1—*Campgrounds and unused sited on National Forests in California studied for changes in habitat 1961-1966*

Study sites	Family units	Elevation	Temperature (1961-1965) max. & min.	Precipitation (1961-1965) avg. annual	Soils depth	Texture	Parent material	Forest types
	No.	*Feet*	*°F.*	*Inches*	*Inches*			
Almanor Campground	98	4,500	100 -11	32.1	+60	0-30 inches clay loam to sandy loam. Below 30 inches gravelly clay to sandy loam	Basaltic	Ponderosa pine-sugar pine-fir (S.A.F. Type 243)[1] White fir predominates Jeffrey pine (S.A.F. Type 247) found in pockets
Clark Fork Campground	34	6,200	([2])	([3])	+48	Sandy loam to loamy sand	Granitic alluvium	White fir (S.A.F. Type 211)
Boundary	0	6,200	([2])	([3])	+48	Sandy loam to loamy sand	Granitic alluvium	White fir (S.A.F. Type 211)
Pinecrest Campground	221	5,600	90 0	35.6	+52	Fine gravelly sand except loamy sand below 14 inches on moist sites	Granitic (terminal moraine)	Ponderosa pine – sugar pine – fir (S.A.F. Type 243)
Summit	0	5,600	90 0	35.6	+52	Fine gravelly sand	Granitic (terminal moraine)	White fir (S.A.F. Type 211)
Laguna	118	5,600	95 0	36.8	+60	Crouch sandy loam and Cuyamca fine sandy loam	Brown decomposed granitic rock	Jeffrey pine (S.A.F. Type 247) with 1/3 of stand being California black oak
Horse Heaven Group Campground	([4])	5,600	95 0	36.8	+60	Crouch sandy loam and Cuyamca fine sandy loam	Brown decomposed granitic rock	Jeffrey pine (S.A.F. Type 247) with 1/3 of stand being California black oak
Drylake (unused site)	0	5,600	95 0	36.8	+60	Crouch sandy loam and Cuyamca fine sandy loam	Brown decomposed granitic rock	Jeffrey pine (S.A.F. Type 247) with 1/3 of stand being California black oak

[1]Society of American Foresters 1954.

[2]Slightly lower than temperatures at Pinecrest.

[3]Slightly higher than average at Pinecrest.

[4]50 to 100 people capacity.

because neither shrubs nor tree and shrub seedlings were found within 50 feet of the center during either sample period.

Ground Cover

The vegetative cover was determined, by species, on 1- by 20-foot belt transects. The basal area of perennial grass species was measured at one-half inch above the soil surface. Frequency and distribution of annual and sod-type grasses were determined within 80 6-inch square quadrats in each transect. The belt transects were also used to measure foliar coverage by shrubs and forbs, area covered by litter and dead wood, and area covered by tree overstory. Overstory coverage consisted of tree foliage more than 5 feet above the sample area. Litter depth was measured at five equally spaced points beginning 15 feet from the camp stove or transect origins. Established shrubs (those more than 6 inches tall and 5 years old) were recorded, by species, on 20-foot square plots.

Seedling Establishment

Seedling establishment for both shrub and tree species was determined within the same plots. In a preliminary study in California, Magill and Nord (1963) found that a critical stage exists between the establishment of new seedlings and their development into saplings. Consequently, I set up two classes of seedlings: (a) Class I seedlings included tree and shrub seedlings that were 5 years old and 6 inches tall or less; (b) Class II seedlings included only tree seedlings that were more than 5 years old and 6 inches tall but less than 1 inch in diameter at 4.5 feet above the ground.

Tree Occurrence and Growth

Tree size-class and species composition were recorded from 20- by 50-foot plots and converted to a per acre basis exclusive of acres in roads, spurs, and other facilities. The size classes used were:

	Diameter breast height *(inches)*
Size classes:	
Saplings	- 1.0 - 4.9
Poles	- 5.0 - 10.9
Small timber	-11.0 - 20.9
Large timber	over 20.9

Growth information was obtained from five dominant or codominant trees nearest to the plot center or stove but within a 50-foot radius. Trees were identified with numbered 1-inch-square aluminum tags placed 6-feet or more above the ground and facing away from the camp stove. Information collected for each tree included species, diameter at 4.5 feet, basal area, height, age, and growth rate (radical increment for 5-year intervals over the past 30 years).

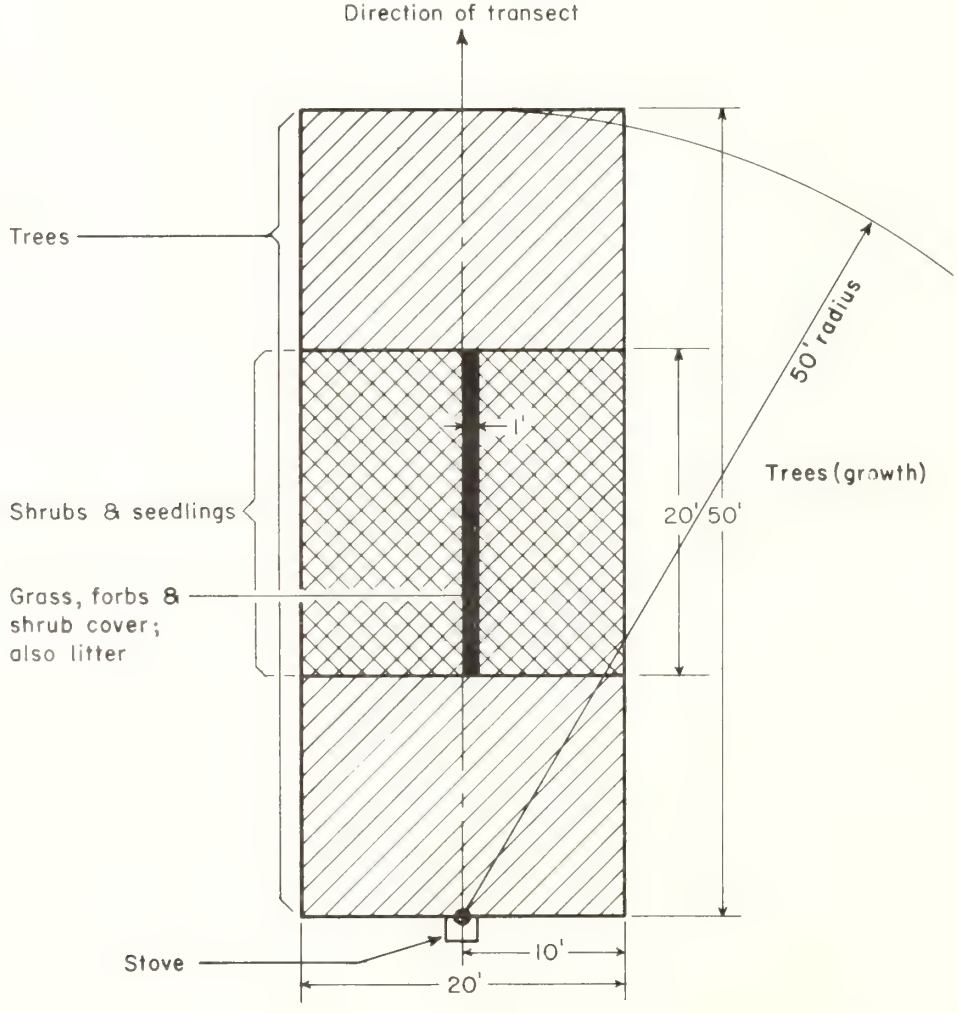

Figure 2–*Study plots were established along transect lines or distributed uniformly through the sites.*

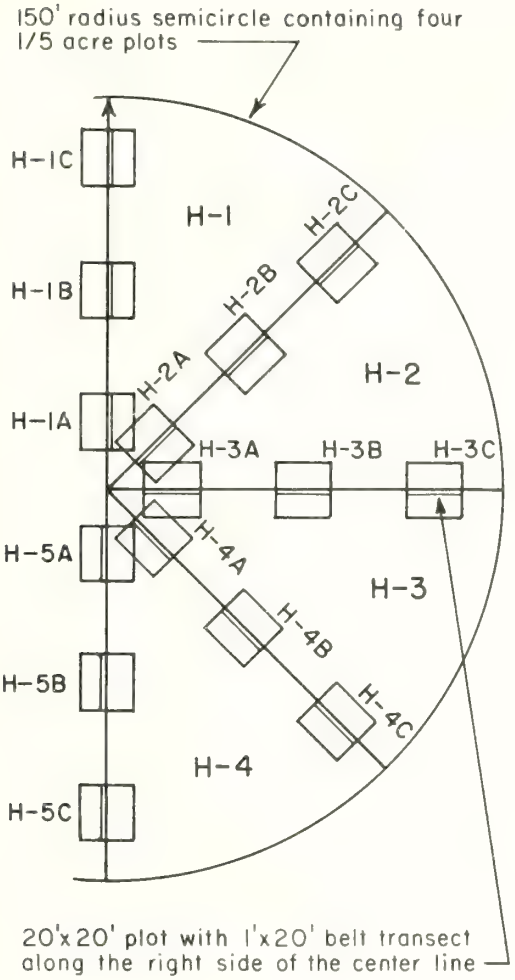

Figure 3—*Plot layout for Horse Heaven. This site could not be sampled in the same way as the others because it is a group campground.*

Screening

Screening is the percentage of the surrounding landscape which is completely masked by vegetation, land forms, or facilities when viewed parallel to the prevailing ground surface. It was measured with a pantallometer or screenometer developed by Nord and Magill (1963). Screening coverage was recorded as the percent of total screening at any given sampling point according to the following types of obstruction categories: tree boles for pole size and larger trees, foliage and twigs of trees and shrubs, and miscellaneous items, such as structures, large boulders, and down timber.

Soils Classification

Standard soil survey procedures were used to determine the soil series. In addition, the soil penetrometer was tried out in the 1966 survey to evaluate soil compaction on the campgrounds. Although the soil penetrometer appeared promising for assessing soil compaction according to an earlier study,[1] results from the present study showed this was not the case except at Pinecrest, where the initial work had been performed. Why the penetrometer test was unsuccessful could only be attributed to variability among soils, soil moisture, and possibly other site factors.

Photography

Permanent photo points were established on each plot to provide a photographic record of any changes in site conditions. The points were identified either by stakes or fixed objects and referenced by permanent objects, such as rocks or trees.

RESULTS AND DISCUSSIONS

Tree Occurrence

Some fluctuations in the numbers of plants ought to be expected as trees grow from one size class to another or are destroyed by insects, diseases, drought, and competition for space, light, and nutrients. Except for epidemic conditions, the resultant changes should be small.

At all campgrounds, the total number of saplings declined *(table 2)*. This decrease might have been predicted after a pilot study in 1961 which found that saplings had been cut for various uses (Magill and Nord 1963). The greatest losses were at Clark Fork Campground (24 percent) and the adjacent unused Boundary site (32 percent). At Clark Fork, the barrier system is made of medium size rocks and logs which the campers have moved, thus allowing them to drive from the roads and parking spurs into the camping area. This ineffective system may account for some of the sapling and seedling mortality. But the losses at both sites suggest that other environmental factors may also be responsible. The only increases

[1] Magill, Arthur W. *Soil compaction in relation to forest recreation.* 1963. (Unpublished M.S. thesis on file at the Univ. Calif., Berkeley.)

Table 2–*Number of trees per acre, by species and size classes, at campgrounds and adjacent unused sites, California 1961, 1966*

Sites[1]	Seedlings I[2]		Seedlings II[3]		Saplings		Poles		Small timber[4]		Large timber[5]	
	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966
						INCENSE-CEDAR						
Almanor	–	–	–	–	3	3	5	5	–	–	–	–
Clark Fork	54	82	11	22	–	–	–	–	–	–	–	–
Pinecrest	11,053	536	7	33	36	25	22	33	11	11	15	15
Boundary	–	–	11	11	11	11	–	–	–	–	–	–
Summit	272	681	446	359	174	185	0	11	–	–	–	–
						WHITE FIR						
Almanor	136	912	207	280	133	125	33	41	27	16	5	11
Clark Fork	1,307	518	316	555	174	152	76	87	0	11	11	11
Pinecrest	336	154	11	25	163	134	91	105	22	25	11	11
Boundary	1,035	790	1,176	1,252	762	566	98	142	0	11	–	–
Summit	109	1,906	152	229	142	131	109	65	22	65	–	–
						PONDEROSA PINE						
Almanor	–	–	24	27	92	82	19	16	8	8	3	3
Pinecrest	–	–	–	–	7	4	25	18	33	33	11	11
Summit	–	–	0	11	22	22	11	11	–	–	–	–
						JEFFREY PINE						
Clark Fork	–	–	0	11	65	54	11	22	–	–	–	–
Laguna	0	27	5	0	38	27	49	49	16	11	–	–
Horse Heaven	0	65	41	21	36	24	20	18	45	48	4	4
Boundary	0	82	98	87	54	33	0	11	–	–	–	–
Drylake	55	245	54	44	44	33	44	44	–	–	–	–
						BLACK OAK						
Pinecrest	0	9	–	–	–	–	–	–	–	–	–	–
Laguna	0	41	49	38	0	5	–	–	–	–	5	5
Horse Heaven	15	123	42	30	–	–	–	–	1	1	11	11
Drylake	1,007	1,090	44	207	–	–	–	–	11	11	–	–

[1]Campgrounds: Almanor, Clark Fork, Pinecrest, Laguna, Horse Heaven. Unused sites: Boundary, Summit, Drylake.

[2]Trees and shrubs 5 years old and 6 inches tall or less.

[3]Trees more than 5 years old and 6 inches tall, but less than 1 inch in diameter and 4.5 feet above ground.

[4]11 to 20.9 inches diameter breast height (d. b. h.).

[5]Over 20.9 inches d. b. h.

in the number of saplings were ascribed to black oak at Laguna Campground and incense-cedar at Summit (unused).

Pinecrest Campground was the only study site where Class I seedlings (less than 6 inches tall and 5 years old) suffered losses. At all the remaining sites, Class I seedlings increased. The change at Pinecrest was not representative because it could be attributed to a single plot at which a clump of trees protected large quantities of incense-cedar, white fir, and lodgepole pine seedlings that had germinated on a small moist area. But, after 5 years, the seedlings had suffered a fourteenfold decrease, possibly as a result of summer drought, disease, and some trampling.

Seedlings not only germinated and survived 5 years on most sites, but apparently advanced into the Class II stage with few exceptions *(table 2)*. Incense-cedar at Summit and Jeffrey pine at Boundary suffered losses, but since they are not recreation sites, the losses may be attributed to other environmental influences. Furthermore, recreational use may not be the cause of Jeffrey pine losses at Laguna and Horse Heaven since similar losses occurred at Drylake, an unused site. On the other hand, Class II black oak seedlings decreased at Laguna by about 22 percent and at Horse Heaven by 29 percent. During the same period the number of plants increased nearly five times at Drylake, and Class I seedlings were increasing

at all three sites. This growth suggests that black oak can successfully germinate in the campgrounds, but may not be able to withstand trampling or other elements of the campground habitat.

Trees in the pole class remained stable or grew more numerous—white fir increased by 16 percent at the three northern campgrounds *(table 2)*. Some minor losses at Almanor, Pinecrest, and Horse Heaven may be attributed to growth into the small timber class or removal after insect infestations. The most notable drop in number of poles occurred at Summit (unused site), but it was countered by an equal increase in the small timber class. The number of trees over 11 inches in diameter remained nearly stable at all sites and for all species. The small changes that did occur were probably not related to recreational use.

Ponderosa pine appears to be susceptible to damage from recreational impact. Class I seedlings were not observed during either sample period at any of the campgrounds. Even though Class II seedlings increased slightly at Almanor between 1961 and 1966 and appeared for the first time at Summit in 1966, they were not found either year at Pinecrest. Furthermore, ponderosa pine poles and saplings growing at Almanor and Pinecrest had decreased by 1966.

Previous work has shown that poor seedling germination and survival may be expected with ponderosa pine (Curtis and Lynch 1965). Evidence from this study does not point to recreational use as a reason for lack of seedlings. However, losses of saplings and poles in the campgrounds may be related to recreational use since the number of trees in both classes remained unchanged at the Summit unused site.

Red fir, scrub oak, willow, and bittercherry were minor stand components on the study sites. Red fir showed slight promise as a durable species. Large red fir at Clark Fork and Class II scrub oak and willow were found at Pinecrest, red fir at Boundary, and bittercherry at Summit.

Two additional observations concern seedlings and saplings. The unused sites (Boundary, Summit, and Drylake) are not true controls. Nevertheless, the gross difference between seedling and sapling counts from the campgrounds and unused sites was so great as to make comparison inevitable. A greater abundance of plants was evident on the unused sites—clearly suggesting that trees below the pole stage found the campground habitat inhospitable.

Usually seedlings grew where protection from vehicular and foot traffic was provided by large rocks, groups of trees, constructed barriers, and clumps of shrubs. Thorny mountain whitethorn often proved to be an effective barrier by fending off visitors.

Tree Growth

The growth rates of trees on the eight study sites did not reveal any changes over a 30-year period that could be directly related to recreational use. Some small changes were noted, but appeared to follow normal growth patterns. For example, growth rates of trees in the younger more open stand at the Summit site were more rapid than that at Pinecrest campground, where the trees are older and more closely spaced. On the other hand, trees at Clark Fork Campground grew faster than those at Boundary. Again, reduced competition for space, this time in the campground, may be responsible for the differences. Similarly, some campground trees with accelerated growth rates were found during a pilot study on the Sequoia National Forest, and the greater spacing between campground plants was believed to be responsible (Magill and Nord 1963). Site development may account for some increased growth, but these studies have not shown recreational use to influence growth rates.

Undergrowth

The combined coverage of forbs and shrubs increased at all sites by 1966. Both groups of plants were detected on the Clark Fork plots for the first time *(fig. 4)*. However, shrubs and forbs covered less than 25 percent of each study site. The coverage increases ranged from 18 percent at Almanor to over 1,000 percent at Laguna. A similar range of increases were recorded for the unused sites. The greatest increases were at the two campgrounds and one unused site in southern California.

Considered separately, shrub coverage at Summit decreased by nearly 11 percent. This may be attributed to competition from trees resulting from an increase in the number of poles and small timber and a 20 percent increase in overstory cover.

Shrub coverage was stable at Clark Fork, Boundary, Laguna, and Drylake, but forb coverage increased on all sites and did so substantially on the three sites in the Laguna recreation area. Shrubs comprised nearly all of the surface area coverage at the northern and central sites, but forbs were of equal or greater importance in southern California. The hot, dry summer climate associated with all of the study areas does not support abundant herbaceous vegetation, but does favor development of extensive brushland or an intermingling of shrubs with widely spaced trees.

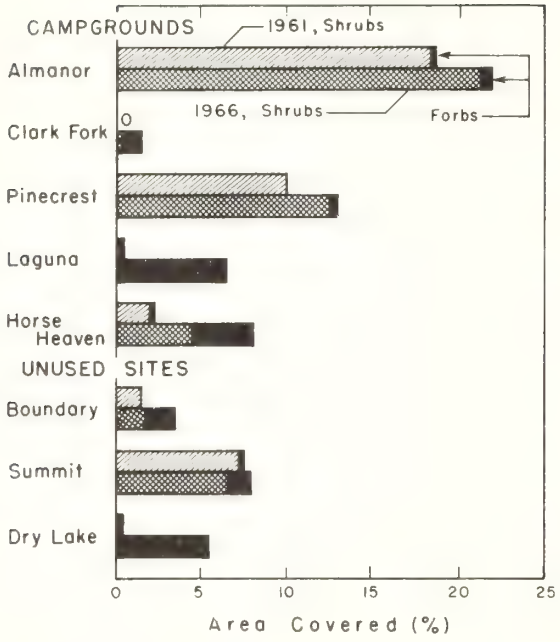

Figure 4–*Percent of area covered by forbs and shrubs on five campgrounds and three unused sites in California in 1961 and 1966.*

Between 1961 and 1966, the number of shrubs per acre decreased 38 percent at Laguna campground and 60 percent at Horse Heaven campground. Yet, shrubs also decreased 86 percent at Drylake (unused), which suggests losses on the campgrounds were not related to recreation use *(fig. 5)*. However, during 1961 and 1966, the total number of shrubs per acre was greater at the southern California campgrounds than at the unused site. Thus, the campground environment may have been more hospitable for shrubs than the unused site.

In northern California, shrubs increased 77 percent at Almanor and 145 percent at Clark Fork, but at Pinecrest there were practically no changes between 1961 and 1966. At Boundary, shrubs increased 38 percent; at Summit they decreased nearly 84 percent. Again this difference suggests that shrubs grow better on campgrounds–possibly because of less competition from tree seedlings, saplings, and poles.

Shrubs Suggested for Study

Some shrubs may merit further study to determine their potential for absorbing the shock of recreational impact. They include mountain whitethorn, sharpleaf snowberry, wood rose, and Sierra chinkapin. In the Western United States where summers are hot and dry, I believe emphasis should be on woody shrubs because they may be able to withstand heavy recreational use and severe climate better than herbaceous plants. Continued study should be directed toward identifying understory species useful for revegetating worn sites or establishing plants on barren recreation sites.

Mountain whitethorn is considered the most promising shrub because it is widely distributed, has a good appearance, has thorns to fend off campers, and may serve as nurse plant for tree seedlings. Results from this study *(tables 3,4)* and observations elsewhere indicate that whitethorn may have potential for withstanding recreational use. Losses of whitethorn at Summit and Boundary (unused areas) suggest that the species may not be tolerant of severe tree competition, and may grow well if it is planted in campgrounds where there is less tree cover.

Growth of snowberry was favorable at three sites. Most of the plants tallied were relatively small, vine-like, without thorns, and growing in well protected locations. Consequently, snowberry should be carefully screened to determine if it can withstand greater exposure to trampling.

Wood rose is armed with fine thorns that may contribute to its usefulness as a visitor control plant. But research is necessary to determine if it resists visitor impact. Future studies should determine if the

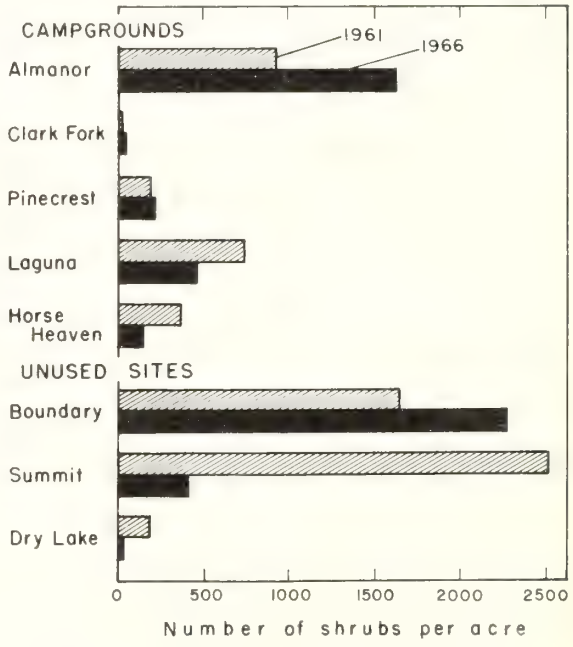

Figure 5–*Number of shrubs per acre on five campgrounds and three unused sites, 1961 and 1966.*

Table 3–*Composition and density of shrubs on campgrounds and unused sites, 1961, 1966*

Species	Almanor		Clark Fork		Pinecrest		Laguna		Horse Heaven		Boundary		Summit		Drylake	
	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966
	Number of plants per acre															
Mountain whitethorn	191	232	27	27	27	91	–	–	–	–	27	0	191	136	–	–
Sharpleaf snowberry	252	463	0	27	–	–	–	–	–	–	1,633	2,232	–	–	–	–
Wood rose	48	211	–	–	18	54	–	–	–	–	–	–	82	191	–	–
Wright Eriogonum	–	–	–	–	–	–	259	231	0	123	–	–	–	–	0	27
Palmer ceanothus	–	–	–	–	–	–	14	14	29	29	–	–	–	–	–	–
Squawcarpet ceanothus	136	177	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sierra chinquapin	225	429	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 4–*Percent of shrub crown area for all plots*

Species	Almanor		Clark Fork		Pinecrest		Laguna		Horse Heaven		Boundary		Summit	
	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966	1961	1966
Mountain whitethorn	9.5	15.1	–	–	10.0	12.1	–	–	–	–	–	–	1.7	0.7
Sharpleaf snowberry	.4	1.0	0	0.1	0	.1	–	–	–	–	1.6	1.9	–	–
Wood rose	1.1	.6	–	–	0	[1]0	–	–	–	–	–	–	–	–
Palmer ceanothus	–		–	–	–	–	[1]0	0	2.0	4.4	–	–	–	–
Squawcarpet ceanothus	5.5	2.0	–	–	–	–	–	–	–	–	–	–	–	–
Sierra chinquapin	1.3	2.6	–	–	–	–	–	–	–	–	–	–	–	–

[1]Indicates values above zero but less than 0.05.

Figure 6.—*Squawcarpet ceanothus* (right foreground) *and mountain whitethorn at Almanor Campground in 1961. Squawcarpet was gone by 1966 , apparently removed by campers clearing tent spaces.*

plant's scraggly appearance is typical or only the result of severe shading.

Sierra chinkapin is a handsome shrub that doubled its areal coverage at Almanor between 1961 and 1966 *(table 4).* It was not found on the other study areas, but should grow at Clark Fork and Pinecrest. Further investigation is necessary to determine its potential for use on recreation areas.

Three other shrubs may deserve some attention. Squawcarpet ceanothus looked like an excellent ground cover plant, but while the number of plants per acre increased, the area covered decreased more than 60 percent. Squawcarpet forms a surface mat beneficial for soil stabilization, but its vulnerability to trampling should be studied *(fig. 6).* Wright eriogonum showed some ability to withstand human impact on the southern California sites. This low growing shrub appeared for the first time at Horse Heaven and Drylake, but decreased in numbers at Laguna. The population of Palmer ceanothus was stable during the study period, but the species' crown area increased by nearly 120 percent. However, the increase could be expected because it is naturally a large spreading shrub and is growing on the perimeter of the camps where visitor influence is probably minimal. Although not an attractive plant, Palmer ceanothus may prove valuable as a screen if new plants can be established and their appearance improved by pruning.

Forbs

During 1966, notable increases in forb occurrence were recorded in all study areas. And 19 species were recorded in the campgrounds for the first time. The increase in herbaceous plants may be related to more favorable weather conditions, the installation of a vehicle barrier system during 1960 and 1961, or both. Undoubtedly, many of the delicate, low-growing forbs would have been crushed and destroyed without the protection offered by the barriers.

In northern California, a few unidentified forbs made the greatest increase in frequency of occurrence. The plants were usually very small and did not have enough parts remaining to allow identification. Though no particular species could be singled out as excelling in frequency or growth, 12 species appeared

for the first time in the campgrounds. Of the 12, only iris had previously been recorded on the unused sites, which also supported four new species not found in the campgrounds. In 1966, a phacelia was the only identified plant not found at Almanor and Pinecrest after being recorded during the 1961 sampling.

In southern California, five forbs appeared to be potentially resistant to recreational use on the basis of their vegetative spread and frequency of occurrence. Foliar coverage by western yarrow, aster, deervetch, and California goldenrod either increased between 7 to 14 times or had invaded the plots on the three study sites by 1966. Deervetch had the largest gain of any species in 1966 *(table 5)*. In 1966, western yarrow and phlox occurred on 60 percent or more of the plots at Laguna, Horse Heaven, and Drylake. Also, deervetch and aster occurred on over 50 percent of the plots at Laguna as did goldenrod and deervetch at Horse Heaven. The same three species had only a 25 percent occurrence at Drylake. During 1966, nine species invaded the campgrounds but mint and clover, which were very sparse on the campgrounds in 1961, were absent in 1966.

Despite their small size, sometimes delicate structure, and frequently sparse distribution, forbs may help stabilize campground soils and add a pleasing touch to the esthetic value of recreation sites. But their tolerance to the impact of recreational use has yet to be determined.

Grasses

Grasses were a minor component of the undergrowth. Their basal area accounted for less than 2 percent of the sample area at all study sites. Apparently not deterred by trampling, sedge increased

Table 5–*Percent of plots stocked by forbs, by campground or site, 1961 and 1966*

Species	1961	1966
ALMANOR CAMPGROUND		
Low Dogbane	6	25
Pacific Monardella	0	12
California Strawberry	6	12
Bigflower Gunsmoke	0	6
Bull Thistle	0	6
Kelloggia	0	6
Whitevein Pyrola	0	6
Unknown spp.	12	6
Phacilia	6	0
CLARK FORK CAMPGROUND		
Unknown spp.	0	75
Bigflower Gunsmoke	0	50
Bluestem Eriogonum	0	25
Clover	0	25
BOUNDARY UNUSED AREA		
Unknown spp.	0	50
Kelloggia	0	25
Pioneer Rockcress	0	25
Western Pipsissewa	0	25
Western Yarrow	25	25
PINECREST CAMPGROUND		
Unknown spp.	0	25
American Adenocaulon	0	17
California Strawberry	0	17
Bigflower Gunsmoke	0	8
Iris	0	8
Minerslettuce	0	8
Sweetroot	0	8
Phacelia	8	0
SUMMIT UNUSED AREA		
Kelloggia	0	50
Iris	50	50
Unknown spp.	0	25
Western Houndstongue	0	25
Barestem Eriogonum	0	25
Braken	0	25
Bigflower Gunsmoke	50	0
LAGUNA CAMPGROUND		
Western Yarrow	62	100
Deervetch	0	80
Phlox	25	62
Aster	25	62
Unknown spp.	12	50
California Goldenrod	0	38
Bigflower Gunsmoke	0	12
Dwarf Ragweed	0	12
Milkvetch	0	12
Paintedcup	0	12
Wyethia	0	12
Mint	12	0
HORSE HEAVEN CAMPGROUND		
Phlox	33	60
California Goldenrod	40	60
Western Yarrow	53	60
Deervetch	0	53
Fleabane	0	33
Bigflower Gunsmoke	0	13
Aster	0	7
Penstemon	0	7
Clover	7	0
DRYLAKE UNUSED AREA		
Phlox	25	100
Western Yarrow	25	75
Unknown	0	50
Deervetch	0	25
California Goldenrod	0	25
Aster	25	25
Gilia	25	0

threefold at Clark Fork and twofold at Boundary. Bluegrass invaded Pinecrest campground, but its basal area contributed only one-tenth of 1 percent. Otherwise, grasses and grasslike plants were stable or decreased at the Sierra sites. Grasses appear to be an important component of the undergrowth at the Laguna recreation area. Sixteen species were found on the three southern California sites, and each species was represented on one or the other campground. However, only four species invaded the campground; six species dissappeared by 1966. Cheatgrass, an abundant annual during the first sampling, decreased in 1966. The basal area of smooth brome increased tenfold at Laguna, thirteenfold at Drylake, and fourfold at Horse Heaven. Needlegrass basal area was stable at Laguna, but increased twenty-eightfold at the Horse Heaven plots and sixfold at Drylake. Smoothbrome, needle grass, and possibly koeleria merit further study to determine trampling resistance.

Soil Surface Coverage

Exposed and often dusty soil surfaces are common for a distance of possibly 10 to 15 feet surrounding family units at many National Forest campgrounds in California. Areas where people concentrate, such as restrooms, water faucets, trails, or campfire circles, are also essentially free of soil cover.

The percent of soil surface covered by plant litter increased between 18 and 32 percent at all campgrounds but Almanor where it increased only 8 percent *(fig. 7)*. Litter coverage at Boundary increased modestly, but at Summit and Drylake it suffered 8 and 2 percent losses. The increase in the area covered by plant litter on the campgrounds is not easy to explain. Raking and trampling spread existing litter over a wider area. In addition, annual litter-fall may have assumed new distribution patterns that were not disturbed by visitor use. Increased precipitation during the 5-year study period, may have stimulated vegetative production and subsequent litter-fall. Considering the upward trends in recreation visits, it is doubtful that litter coverage can increase to the levels that probably existed before site development.

In contrast to areal coverage, changes in litter depth, between 1961 and 1966, showed decreases of 25 percent at Almanor and 29 percent at Pinecrest, and no change at Clark Fork. And at Boundary and Summit the decreases were even greater: 37 and 47 percent, respectively. Similar trends existed in southern California, but the changes were not as great. This suggests that the decrease in litter depth during the study period was not the result of recreational use.

If changes in time are ignored, a comparison of litter coverage and depth on campgrounds and unused sites suggests that camping reduced both *(figs. 7,8)*. The percent of area covered by plant litter was actually greater on the unused sites at each sampling date than on the campgrounds. Furthermore, litter depth was greater at the unused sites on both sampling dates, and it was two to four times greater in 1966 *(fig. 7)*. It may be that recreational impact exerted an influence over a period longer than the 5 years of this study, or during a short period after a campground was opened.

Accumulations of deadwood are another source of soil surface cover. The percent coverage at Pinecrest, Laguna, and Horse Heaven campgrounds was very small and stable. In 1961, deadwood was not found on the Clark Fork plots, but by 1966 it accounted for about 8 percent of the soil cover. Almanor was the only campground which had less deadwood in 1966; the decrease amounted to 50 percent. Increases in deadwood were recorded at the three unused sites; at Drylake by 75 percent; at Summit by 62 percent; and at Boundary by over 4,000 percent. But, at each location the actual area covered by deadwood was very small.

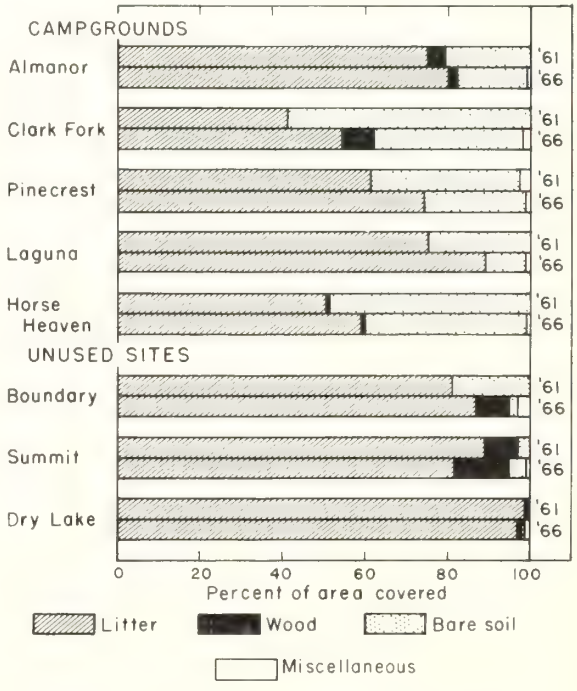

Figure 7—*Percent of soil surface covered by vegetative litter varied widely among the campgrounds and unused sites that were studied.*

The low percentages of deadwood at Pinecrest, Laguna, and Horse Heaven reflect the normal paucity of wood at heavily used campgrounds. As every campground manager knows, piles of wood left in campgrounds are usually gathered and burned by the campers. Naturally, some small pieces remain, and they likely account for the very small area values recorded. At Almanor, slightly higher values for 1961 may reflect the influence of several new units not scavenged, but by 1966, all sites were in use, and wood coverage had been reduced. Natural mortality of pole size and larger trees and some cutting for a new road outside of the campground may account for the increase of deadwood at Clark Fork and Boundary. At Clark Fork, fallen trees that contributed deadwood were recorded only in plot photography, since they were growing adjacent to our plots rather than on them *(fig. 9)*.

What causes the losses of tree seedlings, shrubs, grasses, forbs, and litter on campgrounds? Trampling often is given as the major cause. Another activity that is just as obvious but much less often suggested is tent site clearing. The group camp layout of Horse Heaven illustrated the disturbance wrought by tent site clearings most vividly. Clearings totaled 3,110 sq. ft. of bare soil surface in 1961. Horse Heaven has a 10 to 15 percent slope. Consequently, many of the tent clearings were bordered by small cuts and fills that

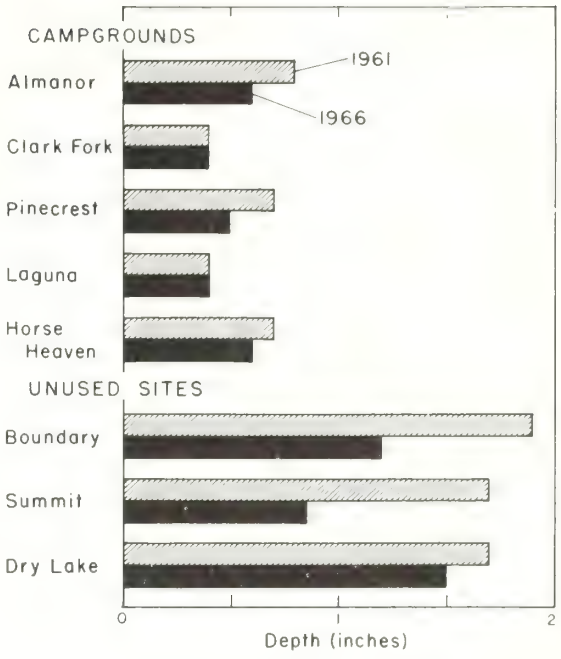

Figure 8 *The unused sites had more litter than any of the campgrounds.*

Figure 9—*Removal of dead or dying trees adds to the deadwood accumulations at campgrounds. Near the woman is the stump of a tree that was felled across the study area.*

Figure 10—*Bare areas occur where campers have prepared tent foundations. Sharp cuts and fills slough away as the site is used.*

tend to slough away under traffic *(fig. 10)*. By 1966, the tent clearings had decreased to 2,356 sq. ft. The original platforms were still present, but tent clearings supporting a sparse cover of new plants and litter were considered stabilized and subtracted from the 1961 area. The campground was opened in 1960 and probably underwent the major clearing during the first or second season. Naturally, tent sites are necessary, but it may be desirable for administrators to build them to minimize vegetation and soil damage.

Soil Compaction

The attempt to establish soil compaction trends, using soil penetrometer and supporting soil moisture information, was generally unsuccessful, as previously mentioned. Yet, a few high penetration resistance values[2] were clearly associated with old roads, trails, or parking areas, and low readings were consistently found beneath clumps of shrubs. Concentrations of vehicles and people obviously compact the soils. However, several studies have shown that soil compaction may not always pose serious problems, and compaction may prove beneficial by effecting greater root firmness and increasing growth rates by providing a greater supply of soil moisture and nutrients and reducing microflora competition for nitrogen (Hartesveldt 1963; Lull 1959; Magill and Nord 1963).

Screening and Overstory Cover

Interunit screening increases ranged between 13 and 37 percent at all but two sites between 1961 and

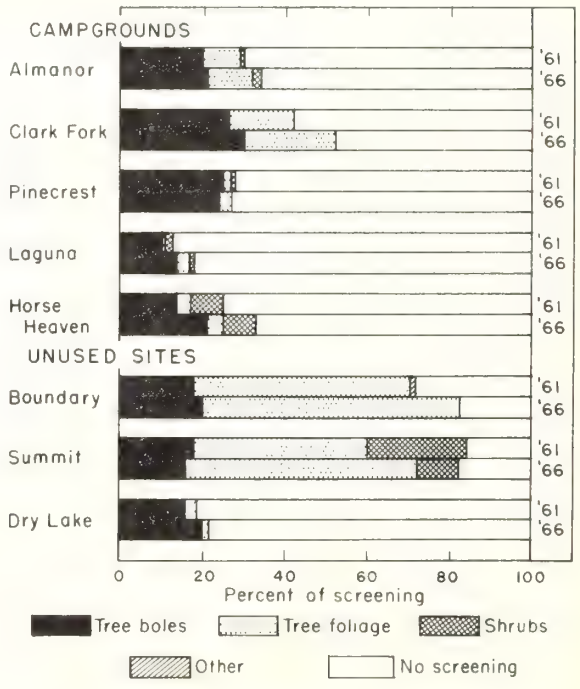

Figure 11 *Percent of campground screening varied at each unit.*

[2]Penetration resistance is defined as the resistance of the soil to the penetration of a steel rod with a known cross-sectional area. The values are computed from the pounds of force required to push the needle into the soil to a given depth. They are recorded in pounds per square inch.

1966. Screening remained generally unchanged at Pinecrest and Summit since losses were less than the 5 percent error inherent in the sampling method *(fig. 11)*. If periodic changes are disregarded, screening was less on the campgrounds than on the unused sites except at Horse Heaven. A comparison between campgrounds and the associated unused sites in 1966, showed that screening was less by 37 percent at Clark Fork, 67 percent at Pinecrest, and 18 percent at Laguna. However at Horse Heaven, it was 54 percent greater than at Drylake. The results suggest that recreational use adversely influenced campground screening, but periodic increases suggest that conditions may be improving.

Tree bole and foliar screening increased between 1961 and 1966, except at Pinecrest campground. Tree boles accounted for over 50 percent of the total screening on campgrounds during both sample years.

Tree foliage provided 50 to 75 percent of the screening on the unused areas except at Drylake. The 76 percent overstory closure of the mixed oak-pine forest at Drylake may have restricted the amount of foliar screening and accounted for the 92 percent screening by tree boles in 1966. Shrub screening was notable only at Horse Heaven and Summit. At Horse Heaven, shrubs provided 8 percent of all screening during both years, while at Summit they had decreased 58 percent by 1966.

SUMMARY AND CONCLUSIONS

The first of the study's objectives—to record changes in campground habitat—was accomplished. The second objective—to identlfy the factors responsible for change—was achieved but only to a limited degree. Our efforts might have been more successful had they been confined to one or possibly two campgrounds. Then the variables could have been examined in greater detail and sampling period scheduled annually.

The study provided a basis for evaluating the effectiveness of barrier systems, for suggesting more intensive studies of plant species potentially tolerant of human impact, and for developing the hypothesis that recreation sites may adjust to or even partially recuperate from heavy recreational use—especially with the occurrence of wet years, some protection, and remedial site treatment.

The potential influence of the barrier systems, installed before 1961, was suggested by the germination and growth of various species of tree seedlings, the increase of forbs and grasses and the invasion of previously unrecorded species on some sites. Apparently, establishment and survival are best where young plants are protected from mechanical injury. But the above-average rainfall in northern California and increasing rainfall in southern California, where precipitation had been below average until 1965, may have contributed to vegetative improvement. Quite likely, the combination of increased available moisture and protection offered by barriers afforded the plants an opportunity to survive human impact.

The study suggests that the "wornout" appearance of campground habitats may only be superficial. True, the greater total amount of tree seedlings and saplings, shrubs, screening, and litter associated with unused sites indicates some environmental decline on campgrounds. But photographic records of the plots show a characteristic sameness between 1961 and 1966 on all sites. Some new plant growth is evident, but losses of litter, soil, and plants are not readily detectable. Photographs show that a few trees have been cut, but factors other than recreational use may be responsible for their forced removal. Tree growth patterns did not show any trends indicating adverse influences from use. These findings agree with Hartesveldt's (1963). However, data from this study do not agree with those of LePage (1962), who reported that in the New Hampshire State Parks, diameter growth responded unfavorably to increasing recreational use and favorably to reductions in use. The improving distribution and cover of undergrowth and the invasion of new species on some sites do correspond with the findings by LaPage (1967) in Pennsylvania. But unlike that study, forbs were a more important component than grasses on the California sites.

The results of this and other studies (Hartesveldt 1963; LaPage 1967) suggest that campground ecosystems may be capable of "adjusting" to human impact. Evidence indicates some actual improvement rather than continued deterioration. Soils tend to be compacted where traffic is concentrated, but this compaction may be beneficial to plant growth.

Barrier systems and an information program asking public forebearance from wood gathering and plant removal or tree scarring are essential for site protection. Accelerated programs for identifying and grow-

ing durable plants as well as establishing effective cultural treatments should prove effective for stabilizing and improving campground habitats.

Investigations of human impact on the soils and vegetation of intensively used recreation sites probably do little more than document the obvious. We had hypothesized that trend studies might be useful in determining campground-carrying capacities. But the variety of environmental conditions associated with outdoor recreation areas, diversity of uses, and varying intensities of impact require that such capacities be determined on a site-by-site basis after intensive study.

A more fruitful approach might be to develop effective means for recreation site management. To develop this means, researchers should stress studies that show managers (a) how to select trees and shrubs that can withstand recreation impact; (b) how to develop effective, practical methods of irrigating, seeding, planting, fertilizing, mulching, and cultivating recreation sites; and (c) how to improve site designs, facilities, and traffic patterns so as to protect sites. At the Pacific Southwest Forest and Range Experiment Station, we plan to close out trend studies and to continue and expand use of this other approach in future recreation research.

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APPENDIX

SPECIES AND WHERE THEY WERE FOUND ON CAMPGROUNDS

Scientific name	Common name	Almanor	Clark Fork/ Pinecrest	Laguna/ Horse Heaven
	ANNUAL GRASSES			
Avena barbata	Slender oat			X
Avena fatua	Wild oat	X		
Bromus mollis	Soft brome			X
Bromus rigidus	Ripgut brome			X
Bromus tectorum	Cheatgrass brome			X
	PERENNIAL GRASSES			
Agropyron spp.	Wheatgrass			X
Agrostis spp.	Bentgrass			X
Bromus carinatus	Mountain brome			X
Bromus spp.	Brome	X		X
Carex spp.	Sedge	X	X	X
Danthonia spp.	Danthonia			X
Elymus spp.	Wildrye			X
Koeleria spp.	Koeleria			X
Muhlenbergia spp.	Muhly			X
Poa spp.	Bluegrass		X	X
Sitanion hystrix	Bottlebrush squirreltail	X		
Stipa lettermanii	Letterman needlegrass	X		
Stipia spp.	Needlegrass		X	X
	FORBS			
Achillea lanulosa	Western yarrow		X	X
Adenocaulon bicolor	American adenocaulon		X	
Ambrosia pumila	Dwarf ragweed			X
Apocynum pumilum	Low dogbane	X		
Arabis platysperma	Pioneer rockcress		X	
Astragalus douglasii	Milkvetch			X
Aster spp.	Aster			X
Castilleja martinii	Paintedcup			X
Chimaphilia umbellata var. *occidentalis*	Western pipsissewa	X		
Cirsium vulgare	Bull thistle	X		
Claytonia perfoliata	Minerslettuce		X	
Cynoglossum occidentale	Western houndstongue		X	
Eriogonum latifolium ssp. *nudum*	Barestem eriogonum		X	
E. wrightii ssp. *membranaceum*	Wright eriogonum			X
Erigeron spp.	Fleabane			X
Fragaria californica	California strawberry	X	X	
Gayophytum diffusum	Bigflower groundsmoke	X	X	X
Gilia spp.	Gilia			X
Iris spp.	Iris		X	
Kelloggia galioides	Kelloggia	X	X	
Lotus nevadensis	Deervetch			X
Lupinus spp.	Lupine			X
Mentha spp.	Mint			X

SPECIES AND WHERE THEY WERE FOUND ON CAMPGROUNDS, continued

Scientific name	Common name	Almanor	Clark Fork/ Pinecrest	Laguna/ Horse Heaven
	FORBS, continued			
Monardella odoratissima ssp. *pallida*	Pacific monardella	X		
Osmorhiza chilensis	Sweetroot	–	X	
Penstemon spp.	Penstemon	–	–	X
Phacelia spp.	Phacelia	X	X	–
Phlox spp.	Phlox		–	X
Potentilla spp.	Cinquefoil	X	–	–
Pteridium aquilinum	Braken	–	X	–
Pyrola picta	Whitevein pyrola	X		
Solidago californica	California goldenrod		–	X
Spraguea umbellata	Umbellate pussypaws		X	
Thermopsis macrophylla var. *semota*	Bigleaf thermopsis		–	X
Trifolium spp.	Clover	–	X	X
Wyethia ovata	Wyethia		–	X
	SHRUBS			
Amelanchier pallida	Saskatoon serviceberry	X	X	
Arctostaphylos patula	Greenleaf manzanita	X	X	–
Artemisia ludoviciana	Louisiana sagebrush		–	X
Castanopsis sempervirens	Sierra chinquapin	X		
Ceanothus cordulatus	Mountain whitethorn	X	X	–
Ceanothus palmeri	Palmer ceanothus			X
Ceanothus prostratus	Squawcarpet ceanothus	X		
Chamaebatia foliolosa	Mtn. misery or Bearmat	–	X	–
Chrysothamnus viscidiflorus ssp. *pumilus*	Low Douglas rabbitbrush		–	X
Lonicera conjugialis	Purpleflower honeysuckle	–	X	
Ribes spp.	Gooseberry	–	X	–
Rosa gymnocarpa	Wood rose	X	X	
Spiraea densiflora	Mountain spiraea	–	X	–
Symphoricarpos acutus	Sharpleaf snowberry	X	X	
	TREES			
Abies concolor	White fir	X	X	–
Abies magnifica	Red Fir		X	–
Libocedrus decurrens	Incense-cedar	X	X	–
Pinus contorta	Lodgepole pine	–	X	–
Pinus jeffreyi	Jeffrey pine	–	X	X
Pinus lambertiana	Sugar pine	X	X	–
Pinus ponderosa	Ponderosa pine	X	X	–
Prunus emarginata	Bittercherry		X	–
Quercus dumosa	Scrub oak	–	X	–
Quercus kelloggii	California black oak		X	X

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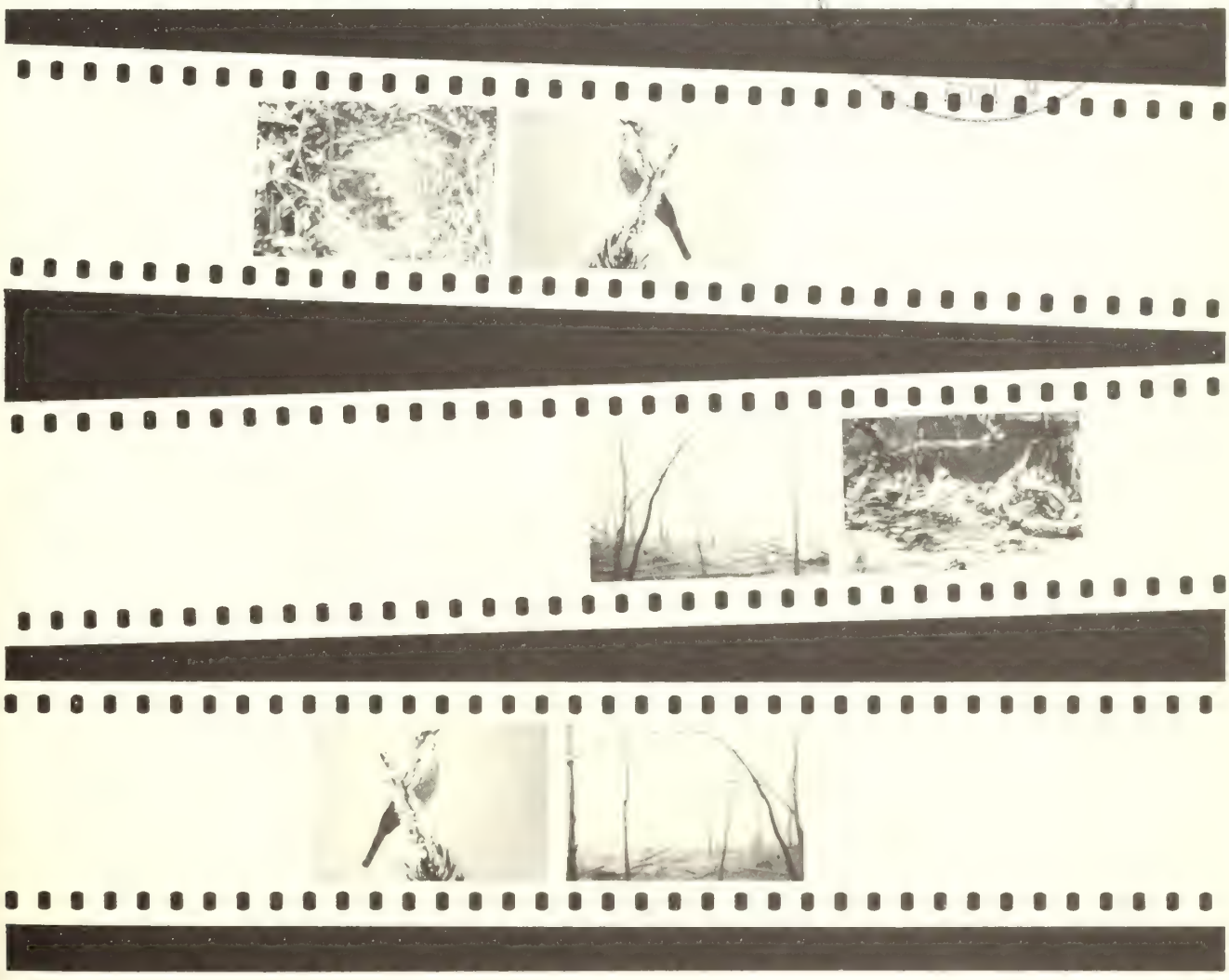
THREE FIRE PREVENTION TELEVISION FILMS VARYING IN "THREAT" CONTENT. . . .

their effectiveness in changing attitudes

Gene C. Bernardi

JUL 15 1971



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The Author

GENE C. BERNARDI, a research sociologist with the Station at Berkeley, conducts studies in the prevention of man-caused forest fires. She holds a bachelor's degree (1951) in psychology and a master's degree (1964) in sociology from the University of California at Berkeley. She joined the Station staff in 1968 after working for the City of Oakland as a research associate (1964-1967).

The campaign to disseminate fire prevention information has for some years relied heavily on a belief in the efficacy of television. Consequently, numerous public service films on fire prevention have been produced and beamed over commercial television channels in the hopes of achieving a reduction in the number of man-caused forest fires. Television continues to be used for this purpose despite a paucity of knowledge about its actual effectiveness in general, or about the effectiveness of various presentation techniques in particular.

The belief in the efficacy of TV can be said to arise out of three assumptions: (a) a TV spot message would be received by a large audience; (b) the proportion of the target population who view the film spots would be even greater than that in the general population because the population considered high risks for starting fire spends an above-average amount of time watching TV (Folkman 1965); and (c) the impact of a television spot would be kept and translated into appropriate behavior when the viewer is in a fire-risk situation.

In 1967, Albert G. Stoll, formerly of the fire prevention research staff, Pacific Southwest Forest and Range Experiment Station, developed three experimental 1-minute television films. The three color films differed in the amount of "threat" content. One film concentrated on portraying wildfire in the process of damaging trees and other vegetation. The second film portrayed intact forest and wildland with wildlife activity, including a scene of two young racoons playing affectionately. A third film alternated between scenes of damaging wildfire, and scenes of an intact forest with some wildlife activity, but stopped short of a "final embrace" by the two racoons. The music in the three films differed, but the narration was the same for all three except for the P.O. Box number and for one sentence that was altered so it related more closely to the content of the film. The changes from one film to the other are given in *italics:*

"No Threat" narration

> If you had told grandfather that someday we would have to pay for space in the street to park the car, he would have laughed at you. But values change in this increasingly populated world of ours and the price is going up on many natural resources besides space. Our forests for example, the ones grandfather used to know. *These lives will go on only if we're careful.* Spread the word. Remind yourself and others to be careful with fire with a free bumper sticker. Send your name and address to Fire Prevention, Box 961, San Francisco, California.

"Mild Threat" narration

> *The seeds of life are there. We can have either this or this.*
>
> *Box 322*

"Threat" narration

> *Can we afford to lose them? Or is their future just a matter of time.*
>
> *Box 154*

To test indirectly the assumptions we made about the use of TV spots two different types of studies were tried. The first study did not draw the amount of response we expected, and so it was abandoned. In the second study—the focus of this paper, we measured the attitudinal responses of a sample of 194 junior college students in northern California. The students completed a questionnaire before and after

seeing the films and an adjective checklist to show their emotional reactions to them. This paper reports the results of these two sets of tests: One on the relative effectiveness of the TV spots, which differed in the amount of "threat" content, in changing attitudes; and the other on whether viewers perceived the films in accord with the film-maker's expectations.

OBJECTIVES

The general objective was to determine the relative effectiveness of three fire prevention TV spots in changing the attitudes of viewers toward one of greater concern for fire prevention. A secondary objective was to answer such questions as: Is the film portraying wildfire and accompanying damage perceived by viewers as frightening or alarming? Does the film portraying flourishing forests and wildlife activity elicit a feeling of optimism (no-threat)? Does the film combining these two situations make the viewer feel somewhat anxious? If one of the films produced attitude change, but did not elicit the emotional reaction expected, then we would need to find out what elements in the film were responsible for producing attitude change.

Scientifically stated, the objective of the study was to test this hypothesis: Positive attitude change is more likely to occur after a strong fear-arousing communication than after a no-threat communication or a mild fear-arousing communication (i.e., one alternating between strong fear-arousing content and non-threatening content). As to the subject matter of the study, the hypothesis may be restated as follows: Attitude change in the direction of greater fire caution will be more pronounced after a strong fear-arousing film (one depicting only damaging wildfire) than after a non-threatening film (forest scenes with no fire depicted) or a mild fear-arousing film (one combining some fire and some intact forest scenes) or than after a control film on an unrelated subject.

METHODS

In the first experiment, the films were exposed over commercial television channels and incorporated a crude measure intended to gauge the proportion of the audience whose attention was attracted to a particular spot. At the end of each film the viewer was asked to send for a free fire prevention bumper sticker. The ratio of requests to estimated viewers, at the time each spot was shown, was to suggest the relative impact of each spot.

Two of the spots were shown in conjunction with popular programs, but only a few requests for bumper stickers were received. Therefore, this first experiment was abandoned, for I felt that the requests for bumper stickers quite likely did not validly measure the attention-getting potential of each spot, but more likely measured the desire for bumper stickers.

In the second experiment, I wanted to test indirectly the third assumption—that TV spots can effect behavior change. Actually, the experimental design incorporated a measurement of attitude change, and therefore was based upon still another assumption—that attitude change is accompanied by consonant behavioral change. Cox (1964, p. 387) points out that attitude change sometimes *follows* behavior change. Furthermore, because I had conducted a laboratory experiment that relied on a captive audience, I could not consider the effect of selective exposure and other predispositional factors which might be counteracted in a laboratory-testing situation (Cox 1964, p. 375-386). The balance of this report concerns this second experiment.

The films' producer chose as the experimental variable the amount of fear-arousal content to be incorporated in each of the three films. He did so because he felt that the motivating force of most fire prevention films is fear—apparently on the assumption that the portrayal of wildfire will arouse an anxiety in the viewer which he will be motivated to reduce.

Several questions need to be answered to test this assumption: First of all, is the information perceived as fearful? If so, does this fear-oriented information of fire prevention films facilitate communication with fire users, especially those who have low knowledge of or poor attitudes toward fire prevention or both? Or might the anxiety created by fear result in the viewer's apparent withdrawal or defensive avoidance of the message? If the fear motive is effective, might there be an optimum level of threat?

Experimental Subjects

This experiment was carried out through the cooperation of five instructors at the Diablo Valley Junior College in Concord, California, who "volunteered" one or more of their classes. These consisted of a psychology, a history, and an anthropology class, as well as several classes each in humanities and social sciences. A total of 194 students participated.

Junior college rather than university students were deliberately chosen in an effort to test a group that might be more likely to have a high incidence of some characteristics of the high fire-risk population in Butte County, California. A survey there showed that the high fire-risk residents tended to be young unmarried persons with a limited amount of schooling for their age (Folkman 1965). If employed, they were apt to have only a part time job in the operative, clerical or laborer occupations, and to have family incomes in the low to medium range. Because junior colleges have no entrance fees and accept all applicants 18 years of age and over, whether high school graduates or not, I felt there might be a higher concentration of persons with these attributes than at a university. Therefore, it might also follow that there would be more persons with low fire prevention knowledge and attitude scores at a junior college than at a university.

The questionnaires completed by the students did not cover all the demographic characteristics obtained in the Butte County survey, but information was obtained on age, marital status, and employment status. In these three categories the students were similar to the Butte County high fire risk population; i.e., 91 percent of the students in this experiment were in the age range 18 to 25 years; 87 percent were single and had never been married; and 69 percent were employed part time or just part of the past year. I could not determine how much schooling they had completed before entering junior college, because 77 percent of the subjects checked 1 to 4 years of college as the highest level of education they had completed. But I assumed that because a high school diploma is not required for junior college entrance that there were some high school drop-outs.

The students tested lower in fire prevention knowledge on three out of four knowledge questions than did the general population in Butte *(see tables 1 to 4 in Appendix).*

On three out of four of the more discriminating attitude statements, a greater proportion of respondents had low (less favorable) before-film attitude scores than did respondents in the Butte County test *(see tables 5 to 8 in Appendix).*

Procedures

To avoid bias that might result from the use of intact classes, the instructors were asked to have their students count off from 1 to 4, and to direct all students with the number one to attend a particular experimental film session, all those with the number two to another experimental film session, and so on. In theory, about equal numbers of each class would be found in each of the four experimental film sessions (one was a control film). In actuality, however, the division was not perfect. Some students who had numbered off (because of time limitations this counting off was done 2 days earlier) probably did not show up for the experiment. And others, who had not been present at the previous class meeting, probably showed up on experiment day, entered their usual classrooms, and remained.

An attitude questionnaire and an Adjective Check List for self report of affective state or emotional disposition were administered to each group before the showing, in the experimental groups, of a fire prevention film, and in the control group, of a neutral non-fire prevention film.[1] After the film showing, the Adjective Check List was again administered. It was followed by a final questionnaire covering knowledge and attitudes regarding fire prevention, recall of film content and other information, and socioeconomic characteristics of the respondents.

Questionnaires and Checklist

"Before" Attitude Questionnaire

The "before" attitude questionnaire was designed to determine the fire prevention attitudes of the subjects before the showing of the films. Entitled *Education, Community, and Environment* this questionnaire consisted of 48 items of which 11 pertained to fire prevention attitudes *(see Appendix).* The remainder were filler items intended to disguise the purpose of the questionnaire, and to interfere, I hoped, with recall of specific answers given to the fire prevention questions which were repeated in the *After Questionnaire.*

A set of attitude statements in which there are five possible responses (strongly agree, agree, undecided, disagree, and strongly disagree) was used (Likert 1967). To avoid response set—a tendency to select

[1] A 1-1/2 minute Animation Workshop color film of abstract designs with a narration of an Ogden Nash poem. Available from the University of California, Extension Media Center, Berkeley.

the same response for all statements–about half of the fire prevention attitude statements were worded so that agreement denoted a favorable attitude, and the remainder so that disagreement denoted a favorable attitude. (The response most favorable to fire prevention was scored 5, and that least favorable was scored 1.)

Six of the 11 attitude statements were selected from the Butte County study (Folkman 1965, p. 30-32). The six questions chosen were among those that were differentiating; i.e., participants in the Butte County study did not all respond to these questions in the same way. The wording was slightly altered in two of the six questions to avoid response set.

Adjective Check List

The *Adjective Check List* has been found to be useful in estimating change in mood or emotional arousal after a variety of experimental treatments.[2] The List used in this study consists of 75 adjectives which describe affect or mood or conscious emotion. Each subject was instructed to check those terms that described the way he felt at that moment. Each adjective falls into one of a number of dimensions representing different moods or emotional states, such as fear, guilt, general excitement, hostility, and depression. Scoring consists in counting the number of adjectives checked which represent the emotional dimensions being measured. Nowlis (1953, p. 126) claims that "the adjective check list seems to succeed by partially freeing the checking behavior from directly controllable verbalizations, in getting groups of responses whose probabilities vary quite directly with changes in conscious emotion or affect."

The adjectives making up the "Fear Cluster"–the emotional state with which this study was most concerned–are alarmed, anxious, apprehensive, fearful, frightened, horrified, scared, startled, threatened, and worried. The adjectives making up the "General Excitement Cluster" (which Haefner[3] found to vary positively with increases in the "Fear Cluster") are disturbed, emotional, excited, nervous, serious, shocked, tense, uneasy, unsure, upset, jittery, and keyed-up.

After Attitude and Informational Questionnaire

An *After Questionnaire* was administered to students immediately after a second Adjective Check List was filled out, following the film showing. It consisted of 31 questions.

It had five questions on reactions to the films seen, 19 questions on the amount of wildland experience of the respondent (including a repeat of the 11 attitude questions in the "before" questionnaire), and seven questions on background or personal information.

Operational Indicators

To test the hypotheses about attitude changes and about the filmmaker's intentions, I used the scoring from the 11 attitude questions and from the two adjective clusters.

Whether a student underwent a positive attitude change toward fire prevention was measured by comparing his "before" and "after" scores on each of the 11 attitude questions. I also measured any change by computing the differences between (a) total "after" and total "before" attitude scores, and (b) summed "after" scores on three differentiating attitude statements and summed "before" scores on these three statements.

To find out which of the 11 attitude statements were the most discriminating I analyzed the results of a pilot test of the questionnaires conducted at Merritt Junior College, Oakland, California. I found that the three statements that best differentiated between students with the most favorable "before" attitude and those with the least favorable "before" attitude were, in order of discriminating ability. . .

1. Fire prevention literature is a waste of taxpayer's money.
2. People should be required to obtain fire permits much on the same basis as drivers' licenses.
3. Schools should not be permitted to use school time for instruction in forest fire prevention.[4]

The three statements were selected by determining the differences between the scores of the 25 highest scorers on the 11 attitude questions and the scores of

[2]Nowlis, V., H. Nowlis, and M. H. Taylor, Jr. *Development of clusters of adjectives for self-report of affective responses. In,* Nowlis, V. Annual status report. Project No. NR 171-342, 1954. As cited by Don P. Haefner, *Some effects of guilt-arousing and fear-arousing persuasive communications on opinion change.* (Unpublished Ph.D. thesis, University of Rochester, New York, 1956.)

[3]Haefner, Don P. *Some effects of guilt-arousing and fear-arousing persuasive communications on opinion change.* 1956.(Unpublished Ph.D. thesis on file at Univ. Rochester, Rochester, New York.)

[4]The smallest difference (i.e., the least discriminating statement) between the extreme high scorers and the extreme low scorers was on the statement "'Smokey Bear' does a good job of alerting the public to fire danger."

the 25 lowest scorers. This method for determining which are the most discriminating statements is called the criterion of internal consistency (Likert 1967, p. 92-95).

I used two types of measures to determine if a particular film aroused in the viewers the emotion intended by the films' producer: one was objective, the other subjective.

The objective measures were the differences between the "after" and "before" scores for each of the two adjective clusters—fear and excitability—within the Adjective Check List. If the film intended to be strong-fear arousing *is* fear-arousing, we would expect those viewing that film to check more adjectives in the two clusters than they had before they saw the film. This should also be true, but to a lesser extent, for those viewing the mild fear-arousing film. Those viewing the no-threat film would be expected to check about the same number of adjectives or fewer in these clusters than they had before seeing the film. And this would be the pattern for the control group if the film chosen, as intended, did not arouse emotion.

The subjective measures of whether each film aroused the type of emotional reaction intended were in the form of these questions:

Which of the following best describes how you felt while viewing the film? Alarmed. . .Somewhat troubled or anxious. . .Neutral or indifferent . . .Contented and/or hopeful. . .Elated.

Did you feel that the message of the film was generally hopeful, neutral, or generally *not* hopeful about solving the man-caused forest fire problem?

Did you feel that the scenes portrayed were *generally* very pleasant, pleasant, unpleasant, or very unpleasant?

RESULTS

Attitude Changes

On only one of the 11 attitude statements did the responses yield a statistically significant difference in the attitude-change scores of the four film groups. This difference occurred in response to the statement: "Where the countryside or forests are green one need not worry about discarding cigarette butts or used matches on the ground."[5]

Most students did not change their attitude toward this statement after viewing the films. The size of the no-change groups ranged from three-fifths of the Control film viewers to three-fourths of the "Threat" film viewers *(table 9 in Appendix; fig. 1).*

In all film groups, except the "No Threat" film group, the largest proportion of those whose attitude changed shifted to a less favorable position (a lower score) on that statement than they had held before the film. This was particularly true in the Control film group. All but one of those respondents whose attitude changed had a slightly less favorable attitude toward this statement after viewing the Control film.

Computation of the Mann Whitney U test[6] of significance on individual pairs of fire prevention film groups revealed no statistically significant differences between the film groups when paired. Although the fire prevention films did not differ significantly from each other in their resulting distribution of attitude-change scores, each did differ significantly from the Control film.[7] The most significant difference occurred between the "No Threat" film group and the Control group.

I interpret these findings to mean this: A respondent's attitude on fire prevention when tested before and after a film, is less likely to decline in favorableness after viewing a film on fire prevention than after viewing one on a totally unrelated subject. Responses to the statement "Where the countryside or forests are green, one need not worry about discarding cigarette butts and used matches on the ground" would seem to support this interpretation. In fact, the "No threat" film was the only one in which the shift to a more favorable attitude was greater than the shift to a less favorable attitude after film viewing.

An analysis of the "before" attitudes toward this statement *(table 10 in Appendix)* reveals, however, that the results may not be due to the effect of the "No Threat" film but rather to the fact that viewers of the "No Threat" film had more opportunity for change to a more favorable attitude than viewers of

[5]The Kruskal-Wallis One-Way Analysis of Variance Test of Statistical Significance was used—this yielded an H of 12.66 which, with df = 3, shows $0.001 < P < .01$ (Siegel 1956, p. 184-194).

[6]The Mann Whitney U test for two independent samples, like the Kruskal-Wallis One-Way Analysis of Variance for k independent samples, is performed on ungrouped data and has the same power-efficiency, i.e., about 95.5 percent (Seigel 1956, p. 116-127).

[7]"Mild Threat" vs. Control [$P(Z \geq 1.54) = .06$]; "Threat" vs. Control [$P(Z \geq 1.78) = .04$]; "No Threat" vs. Control [$P(Z \geq 2.72) = .003$].

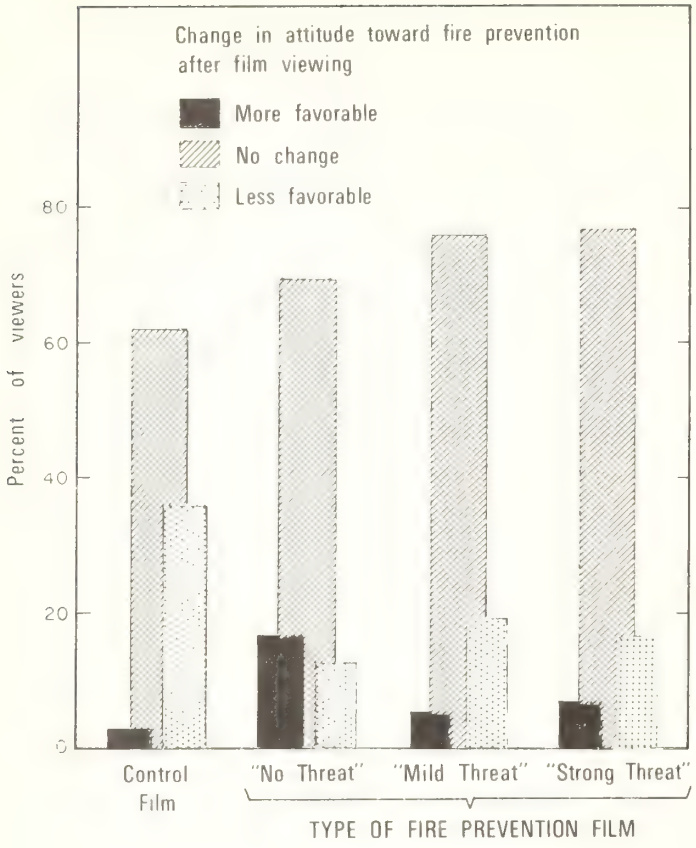


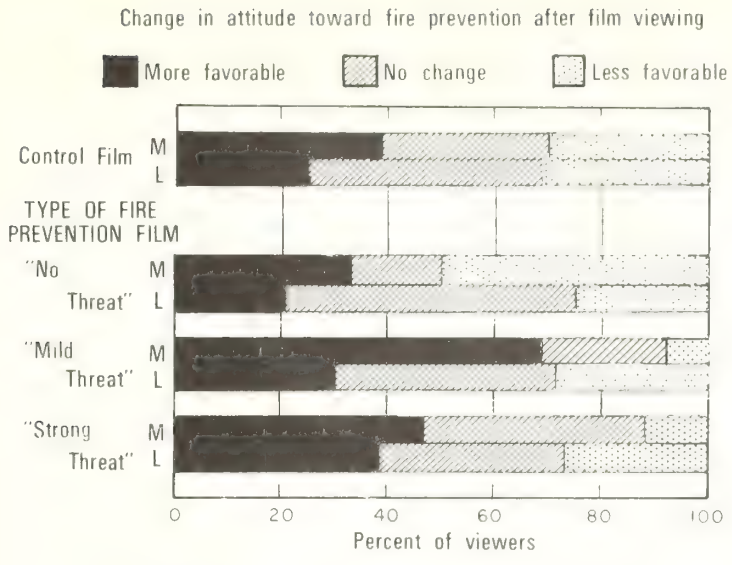
Figure 1—*Three fire prevention films were not very effective in producing a more favorable attitude toward fire prevention. But, any one of them was more effective than the Control film. Of the three fire prevention films the "No Threat" film was significantly more effective than the Control film. Attitude change was measured by calculating the difference between the before and after response scores on the statement "Where the countryside or forests are green one need not worry about discarding cigarette butts and used matches on the ground."*

the other films. The attitude statement "Where the countryside or forests are green, one need not worry about discarding cigarette butts or used matches on the ground" evidently was not a discriminating statement. Among the students tested, all but two persons either disagreed or strongly disagreed with the statement; most subjects strongly disagreed with it. In the "No Threat" group, however, only 63 percent strongly disagreed with it before seeing their film (another one-third merely disagreed with it); in the other film groups 76 percent to 84 percent strongly disagreed with the statement and the balance merely disagreed with it before seeing their films.

Comparing the four film groups' attitude-change scores in response to the 10 other attitude statements taken singly, or when summed for a total score on all 11 statements, or on the three differentiating statements, I found that *no one film changed attitudes significantly more than any other film including the Control film.*

The criterion of a film's effectiveness is subsequent positive attitude *change*, and does not include mere maintenance of prior attitude. Nevertheless, it should be noted (since it parallels the finding reported in the following section concerning anxiety reactions to the films) that, when those students showing no change in their total attitude score are grouped with those who show a favorable attitude change, the resulting proportion of students becomes progressively larger as the subject matter changes from non-fire prevention to fire prevention and as the amount of threat content increases. Those showing a favorable attitude change together with those showing no attitude change made up 1/3 of the Control group, more than 2/5 of the "No Threat" group, 1/2 of the "Mild Threat" group, and 3/5 of the "Threat" group. The importance of this progression, of course, depends upon whether those experiencing no change have an initially favorable (high total score) or unfavorable (low total score) fire prevention attitude, i.e., the maintenance of a poor attitude is not indicative of film effectiveness.

When the students were categorized according to whether or not the message was relevant to them, I found some significant differences in attitude change where attitude change is indicated by the differences between the summed "before" and summed "after" response scores on three differentiating attitude



M= Viewers to whom fire prevention is more relevant because they lived or worked in wildlands in past year

L= Viewers to whom fire prevention is less relevant because they did not live or work in wildlands in past year

Figure 2 *A "Mild Threat" fire prevention film was the most effective in producing favorable attitude change among students who had recently worked or lived in wildlands. The differences between the effects of the "Mild Threat" film and the "No Threat" film were statistically significant. Attitude change was measured by calculating the difference between the summed "before" and summed "after" response scores on three differentiating attitude statements.*

statements.[8] Used as an indicator of relevance was the question "Did you live or work in any forest or other wildland areas during the past year?" When individual pairs of treatments were compared, a significant difference in the effects of the "Mild Threat" and "No Threat" films was shown– $0.02 < P \ (H \geq 8.52, df = 3) < .05$.[9] This difference is apparently due to the contrasting responses of the subject for whom prevention of fire is relevant *(fig. 2)*. In the "Mild Threat" group, 92 percent of those subjects for whom fire prevention is more relevant either showed no change in their before film attitude or changed to a more favorable attitude, whereas only 50 percent of the 'more relevant' subjects viewing the "No Threat" film were in these categories. In seeking an explanation for the greater effectiveness of the "Mild Threat" film a check of the fear-arousing potential of each of the films revealed that the "Mild Threat" film produced less alarm and anxiety *(table 11 in Appendix)* than either the "No Threat" or the "Threat" films. Approximately equivalent proportions of students viewing the "No Threat" and "Threat" films experienced an increase in anxiety after their film. This proportion exceeded that in the groups viewing the "Mild Threat" and Control films. One might conclude that the so-called "No Threat" film's anxiety provocation was compensated for by a reaction of defensive avoidance (Janis and Feshback 1953) except that the "Threat" film, which produced an equivalent proportion experiencing anxiety increase, did not produce an accompanying defensive avoidance.

The "Mild Threat" film was more effective than the "No Threat" film in producing favorable attitude change among students who had lived or worked in forest or wildland areas recently. The "Threat" film appears to have been next most effective with this higher relevance group. Among these students, not only was there favorable attitude change in response to the "Threat" film, but unlike in the "No Threat" group, there was a sizable proportion who retained their "before" film attitudes. These findings appear to contradict those of Berkowitz and Cottingham (1960), who found that a strong threat was more effective than a weak one only among the *low* relevance subjects, i.e., those who had little experience with the subject matter.

Fear-Arousing Potential

Differences between the four film groups in the

[8]The Kruskal-Wallis One-Way Analysis of Variance Test of Statistical Significance was used– this yielded an H of 19.82 which, with df = 6, shows $.001 < P < .01$.

[9]The "Mild Threat" film effects are also significantly different from those of the Control film [$.02 < P$ ($H \geq 8.32$, $df = 3$) $< .05$].

direction and amount of change in the number of fear adjectives or excitability adjectives checked after the film showing were not statistically significant.

Students who saw the fire prevention films, tended, however, to check more, or the same number, rather than fewer fear adjectives than those who saw the Control film. And this tendency increased as the amount of threat content in the film increased:

- More than 75 percent of those viewing the "Threat" film showed no change or checked a few more fear adjectives than before viewing their film.
- More than 66 percent of students in both the "Mild Threat" and "No Threat" film groups showed no change or checked a few more fear adjectives after viewing their films.
- Less than 60 percent of students in the Control group checked the same number or a few more fear adjectives than they had before viewing their film.
- The "Threat" and the "No Threat" film groups had the highest proportions checking more fear adjectives after seeing their films: 51 percent and 41 percent, respectively. The percent showing no change or checking a few more or a few less fear adjectives after viewing film:

Film Group:	No change	A few more	A few less
"Threat"	26	51	23
"Mild Threat"	41	28	31
"No Threat"	26	41	33
Control	22	36	42

The most pertinent subjective measure of a viewer's reaction to a film was his response to the question about how he felt while viewing the film: alarmed, somewhat troubled or anxious, neutral or indifferent, contented and/or hopeful, or elated? While the differences in reactions reported were not significant at the 5 percent level, the probability of their occurring by chance was less than 10 percent. However, the differences found were not those expected *(see table 11 in Appendix).* The "No Threat" film rather than being the least threatening had the greatest proportion (10 percent) of students who reported feeling "alarmed" while viewing their film. In fact, when the two categories 'alarmed' and 'somewhat troubled or anxious' are grouped together, the proportions of students in the "No Threat" and the "Threat" film groups reporting these feelings were virtually equal (about 44 percent).

The most typical reaction expected in response to the "Mild Threat" film was feeling 'Somewhat troubled or anxious.' However the "Mild Threat" film evoked this response from a smaller proportion than did the "No Threat" or "Threat" films. A large proportion (47 to 51 percent) in all groups but the "No Threat" group reported they were 'neutral or indifferent' while viewing their film.

I used three other subjective measures of reactions to the films. They were the responses to these questions: (1) Did you feel that the message of the film was generally hopeful, neutral, or generally *not* hopeful about solving the man-caused fire problem? (2) Did you feel that the scenes portrayed were *generally* very pleasant, pleasant, unpleasant, or very unpleasant? (3) How interesting was this film to you: very interesting, somewhat interesting, not very interesting, not at all interesting? The differences in responses among the four film groups were statistically significant.

The largest proportion—51 percent—of any group feeling that the film it viewed had a hopeful message about solving the man-caused fire problem was in the "Mild Threat" film group *(table 12 in Appendix).* Another 35 percent of the group felt the film was neutral and 14 percent felt it was not hopeful.

The largest proportion—44 percent—of any group feeling that its film's message was not hopeful was in the "Threat" film group. The remainder (56 percent) was divided equally between those who thought the film neutral and those who thought it hopeful.

The "No Threat" film group had the smallest proportion (about 25 percent) feeling the film was neutral; 39 percent felt it was hopeful, and 37 percent felt it was not hopeful. Almost half of the respondents in the Control film group felt their film was neutral in solving the man-caused forest-fire problem; 40 percent thought it not hopeful, and 9 percent thought it hopeful.

As to whether the scenes portrayed were perceived as very pleasant, pleasant, unpleasant, or very unpleasant, 91 percent of the "Threat" film group reported them as either unpleasant or very unpleasant. The "Mild Threat" group was split—half reported some degree of unpleasant and half some degree of pleasant. In the "No Threat" film group, 84 percent reported the scenes were pleasant or very pleasant; and 14 percent, that they were unpleasant. In the Control group, 53 percent reported the scenes pleasant; and 47 percent, that they were unpleasant *(table 13 in Appendix).*

Among the fire prevention film groups the proportion of students who considered their film very interesting or somewhat interesting decreased as the amount of "threat" was increased. Over four-fifths of the "No Threat" film group found their film interesting, whereas three-fourths of the "Mild Threat" group and two-thirds of the "Threat" group found their films interesting *(table 14 in Appendix).*

DISCUSSION AND CONCLUSIONS

Results of experiments on attitude and behavioral change using fear-arousing techniques have not been consistent: Some of the earliest work by Janis and Feshback (1953, 1954) suggested that high-fear arousal produced less attitude change, presumably because high fear produced responses of defensive avoidance. Goldstein (1959), Janis and Terwillinger (1962) and Nunnally (1961) reported similar findings. Berkowitz and Cottingham (1960) found that a communication with strong fear appeal produced more attitude change than one with a weak fear appeal, but this held only for those to whom the communication was of low relevance. Others who have reported that strong fear arousal made attitude changes easier include Chu (1966),DeWolfe and Governale (1964), Leventhal and Niles (1965), Leventhal, Singer and Jones (1965), Piccolino (1966), and Powell (1965). Leventhal, Singer and Jones' study found that although fear produced attitude change, it did not produce behavioral change unless combined with specific plans for action.

Chu's (1966) study adds additional variables to early research on fear arousal. He found that the more a person saw a means of averting threat, the greater was the effect of a strong fear-arousing communication. But, although a mild fear arousal communication was less effective than one with a strong fear arousal, the attitudes achieved were more resistant to counterpropaganda.[10]

In this study the so-called non-threatening film with scenes of wild animals, birds, and intact forests and *no* wildfire was perceived as the most pleasant and the most interesting film. And it was perceived to be just as threatening as the so-called threatening film with its damaging wildfire scenes. These findings suggest that if one wishes to test the effectiveness of threat in producing change, one may be just as successful in creating the test variable by using *implied* threat to valued objects, rather than using the apparently scarier scenes of damaging wildfire. Miller (1963) suggests that researchers should "Stop and back up a step...rather than assuming that 'everyone knows a fear appeal when he sees one'...." He feels that rationales should be developed for labeling certain classes of stimuli as "universally" anxiety-arousing. He had been investigating the possibility that cues denoting social approval fall in this category.

Regardless of how the films were perceived by their respective audiences, no one film in this study could be considered superior to another in its attitude-changing effectiveness for the audience as a whole. But for those subjects who had recently lived or worked in forest or wildland areas, the "Mild Threat" film was most effective in producing favorable attitude change. Since prevention of fire was relevant (by criterion: recently lived or worked in wildlands) for less than one-third of the students, perhaps we may draw these conclusions:

- A "Mild Threat" film may be the most successful (compared to a "No Threat" or a "Strong Threat" film) in improving fire prevention attitudes among groups of persons living, working, or presently camping in wildland areas.
- For high fire risk persons who are not currently camping, or who are not known to have recently lived or worked in wildland areas, we must find ways to make fire prevention relevant by associating it, in our messages, with subject matter known to be relevant to this target population.

SUMMARY

Bernardi, Gene C.

1970. **Three fire prevention television films varying in "threat" content... their effectiveness in changing attitudes.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 26 p., illus. (USDA Forest Serv. Res. Paper PSW-63)

Oxford: 432.13:U301.153–U654.197.
Retrieval Terms: fire prevention education; television research; threat appeals; attitude change.

[10]For an excellent review of the last 15 years of fear arousal research, see Higbee (1969).

An experiment to test the relative effectiveness in changing attitudes of three fire prevention TV films intended to vary in the intensity of threat portrayed (none, mild, and strong) was conducted among 194 junior college students in California. A fourth film, not concerned with fire prevention, served as the control film.

The scenes of the three fire prevention films, each in color and lasting 1 minute, differed in content and musical background. The narration for the three films was the same except for the P.O. Box number and for one sentence.

The hypotheses that (a) the films would elicit the emotions intended by the producer and that (b) the film intended to have the strongest threat would be the most effective in producing positive attitude change, were not confirmed.

A significant difference among the four film groups in attitude change occurred in response to only one out of the 11 attitude statements used. This significant change to a more favorable attitude occurred in the group that viewed the "No Threat" film. But this change could not be attributed to the superior effectiveness of the "No Threat" film because of the distribution of attitudes in this group before the film was viewed. The proportion of viewers in the "No Threat" film group who were *able* to move to an even more favorable position after film viewing was twice as large as that in the "Mild Threat" and "Strong Threat" film groups. When the responses of students who had lived or worked in wildlands recently were compared with those of students who had not, the "Mild Threat" film was found to be significantly more effective than the "No Threat" film in producing favorable attitude change among those for whom fire prevention was apparently more relevant.

Neither an objective measure—checking off items in an Adjective Check List—nor the most direct subjective measure—asking each subject how he felt while viewing the film—resulted in any significant differences among the four films in the extent of anxiety reaction experienced. However, both of these measures indicated that the "No Threat" and "Threat" films tended to produce an approximately equivalent proportion experiencing an anxiety reaction. And this proportion was greater than that expressed by either the "Mild Threat" or Control groups. There was apparently greater potential in the "No Threat" film for arousing some kind of emotional reaction, whether anxiety or hope-oriented, rather than mere indifference or neutrality.

Significant differences were also found in the other less direct subjective measures of students' emotional reactions to the films. The degree of pleasantness perceived and the amount of interest in a film seemed to vary together. The largest proportion (83 percent) experiencing the film viewed as both pleasant and interesting was in the "No Threat" group. Both the perception of pleasantness and the amount of interest decreased as the threat content of the films was increased.

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APPENDIX

Table 1—*Answers to question on the flammability of green trees and shrubs in California*

Answer chosen	Junior College students who saw film . . .					Butte County survey respondents[1] (N=761)
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)	
	Percent					
Correct ("will catch fire and burn very rapidly")	60.0	46.9	47.4	51.1	51.0	43.4
Incorrect	22.2	24.5	24.6	23.3	23.7	48.9
Don't know	17.8	28.6	28.0	25.6	25.3	7.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1] See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 2—*Answers to question on potential of starting a fire by driving in dry grass*

Answer chosen	Junior College students who saw film . . .					Butte County survey respondents[1] (N=761)
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)	
	Percent					
Correct (both exhaust and friction sparks set fires)	37.8	55.1	43.9	55.8	47.9	61.8
Incorrect	37.8	22.5	26.3	23.3	27.3	27.0
Don't know	24.4	22.4	29.8	20.9	24.8	11.2
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1] See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 3—*Answer to question on the surest way to put out a campfire*

Answer chosen	Junior College students who saw film . . .					Butte County survey respondents[1] (N=761)
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)	
	Percent					
Correct ("Pour water on it and stir thoroughly")	24.5	20.4	19.3	30.2	23.2	56.6
Incorrect	71.1	77.6	75.4	67.5	73.2	42.6
Don't know	4.4	2.0	5.3	2.3	3.6	.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1] See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 4—*Answers to question on when fire permits are required*

Answer chosen	Junior College students who saw film . . .					Butte County survey respondents[1] (N=761)
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)	
	Percent					
Correct (all types of fires)	20.0	40.8	28.1	23.3	28.4	58.7
Incorrect	46.7	30.6	38.6	46.5	40.2	32.0
Don't know	33.3	28.6	33.3	30.2	31.4	9.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1]See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta. Berkeley, Calif. 32 p. 1965.

Table 5—*Responses of Junior College students and Butte County, California, residents to statement: "Forest fire danger in California open country is highly overrated"*

Attitude[1]	Junior College	Butte County[2]
	Percent	
Strongly disagree (5)	57.2	16.3
Disagree (4)	32.5	56.2
Undecided (3)	5.7	18.4
Agree (2)	1.5	5.4
Strongly agree (1)	2.6	2.0
No answer given	.5	1.7
Total	100.0	100.0

[1]Score (5) represents the most favorable attitude.
[2]Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 6—*Responses of Junior College students and Butte County, California, residents to statement: "People should be required to obtain fire permits much on the same basis as drivers' licenses"*

Attitude[1]	Junior College	Butte County[2]
	Percent	
Strongly agree (5)	10.3	16.2
Agree (4)	38.1	44.7
Undecided (3)	21.7	13.0
Disagree (2)	25.3	24.0
Strongly disagree (1)	3.6	1.8
No answer given	1.0	.3
Total	100.0	100.0

[1]Score of 5 represents the most favorable attitude.
[2]See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 7–*Responses of Junior College students and Butte County, California, residents to statement: "Fire prevention literature is a waste of taxpayers' money"*

Attitude[1]	Junior College (N=194)	Butte County[2] (N=761)
	Percent	
Strongly disagree (5)	19.6	29.1
Disagree (4)	58.2	61.9
Undecided (3)	15.5	4.3
Agree (2)	6.2	2.0
Strongly agree (1)	.0	2.5
No answer given	.5	.1
Total	100.0	[3]100.0

[1]Score of 5 represents the most favorable attitude.
[2]See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention*. U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.
[3]Columns may not add to 100.0 because of rounding.

Table 8–*Responses of Junior College students and Butte County, California, residents to statement: "Schools should not be permitted to use school time for instruction in forest fire prevention"*

Attitude[1]	Junior College (N=194)	Butte County[2] (N=761)
	Percent	
Strongly disagree (5)	22.7	24.4
Disagree (4)	62.4	64.1
Undecided (3)	9.8	4.7
Agree (2)	4.6	4.7
Strongly agree (1)	.0	1.6
No answer given	.5	.5
Total	100.0	100.0

[1]Score of 5 represents the most favorable attitude.
[2]See Folkman, William S. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention*. U.S. Forest Serv. Res. Paper PSW-25, Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 32 p. 1965.

Table 9–*Respondents' changes in attitude about fire prevention as measured by change in attitude toward statement: "Where the countryside or forests are green, one need not worry about discarding cigarette butts and used matches on the ground"*

Attitude after film	Junior College students who saw film[1] . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
More favorable	2.2	16.3	5.3	7.0	7.8
No change	62.2	69.4	75.4	76.7	71.1
Less favorable	35.6	12.3	19.3	16.3	20.6
No answer given		2.0	-		.5
Total	100.0	100.0	100.0	100.0	100.0

[1]The Kruskal Wallis One-Way Analysis of Variance test of statistical significance was applied to ungrouped data (attitude change scores ranged from -4 to +2). This yielded an H of 12.66 which, with df = 3, shows $.001 < P < .01$.

Table 10–*Respondents' attitude about the statement "Where the countryside or forests are green one need not worry about discarding cigarette butts or used matches on the ground" before they saw films*

Responses	Junior College students before saw film . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
Strongly disagree	75.6	63.3	82.5	83.7	76.3
Disagree	22.2	32.7	17.5	16.3	22.2
Undecided	2.2	2.0	–	–	1.0
Agree	–	–	–	–	–
Strongly agree	–	–	–	–	–
No answer given	–	2.0	–	–	.5
Total	100.0	100.0	100.0	100.0	100.0

Table 11–*Answers to question: "Which of the following best describes how you felt while viewing the film?"*

Answer chosen	Junior College students who saw film[1] . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
Alarmed	2.2	10.2	5.3	4.7	5.7
Somewhat troubled or anxious	17.8	32.6	26.3	39.5	28.9
Neutral or indifferent	51.1	28.6	47.4	46.5	43.3
Contented and/or hopeful	20.0	24.5	17.5	7.0	17.5
Elated	8.9	4.1	1.8	2.3	4.1
No answer given	–	–	1.7	–	.5
Total	100.0	100.0	100.0	100.0	100.0

[1]Kruskal Wallis One-Way Analysis of Variance test of statistical significance yielded an H = 7.75 which, with df = 3, shows .05 < P < .10.

Table 12–*Answers to question: "Did you feel the film message was hopeful about solving the man-caused fire problem?"*

Answer chosen	Junior College students who saw film[1] . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
Generally hopeful	8.9	38.8	50.9	27.9	33.0
Generally neutral	48.9	24.5	35.1	27.9	34.0
Generally *not* hopeful	40.0	36.7	14.0	44.2	32.5
No answer given	2.2	–	–	–	.5
Total	100.0	100.0	100.0	100.0	100.0

[1]Kruskal Wallis One-way Analysis of Variance test of statistical significance yielded an H=20.20 which, with df=3, shows P < .001.

Table 13—*Answers to question: "Did you feel the scenes portrayed were generally . . . ?"*

Answer chosen	Junior College students who saw film[1] . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
Very pleasant	2.2	36.7	8.8	2.3	12.9
Pleasant	51.1	47.0	40.4	7.0	37.1
Unpleasant	35.6	12.3	35.1	53.5	33.5
Very unpleasant	11.1	2.0	14.0	37.2	15.5
No answer given		2.0	1.7		1.0
Total	100.0	100.0	100.0	100.0	100.0

[1]Kruskal Wallis One-Way Analysis of Variance test of statistical significance yielded an H=60.20 which, with df=3, shows $P<.001$.

Table 14—*Answers to question: "How interesting was this film to you?"*

Answer chosen	Junior College students who saw film[1] . . .				
	Control (N=45)	"No Threat" (N=49)	"Mild Threat" (N=57)	"Threat" (N=43)	Total (N=194)
	Percent				
Very interesting	13.3	20.4	24.6	18.6	19.6
Somewhat interesting	31.1	61.2	52.6	46.5	48.5
Not very interesting	37.8	18.4	12.3	32.6	24.2
Not at all interesting	15.6		8.8	2.3	6.7
No answer given	2.2		1.7	–	1.0
Total	100.0	100.0	100.0	100.0	100.0

[1]Kruskal Wallis One-Way Analysis of Variance test of statistical significance yielded an H=13.44 which, with df=3, shows $.001 > P > .01$.

EDUCATION, COMMUNITY, AND ENVIRONMENT

Directions: Below you are presented with a series of statements or opinions. Read each statement. Then mark an X in the box (as follows: [X]) after that one of the provided alternatives: Strongly agree [ ], Agree [ ], Undecided [ ], Disagree [ ], or Strongly disagree [ ], which best describes your feeling about the initial statement.[1]

(NOTE: The word esthetic[2] as used in this questionnaire has reference to the beautiful or to the appreciation of the beautiful.)

1. The goals of education should be dictated by children's interests and needs as well as by the larger demands of society.

2. The more education a person has the better able he is to enjoy life.

3. Everyone should have a little training in esthetic matters.

4. There are too many fads and frills in modern education.

5. Education helps a person to use his leisure time to better advantage.

6. Schools today are neglecting the three R's.

7. Education helps one enjoy the beauty of natural and man made things, such as sunsets, landscapes, music, paintings and sculpture.

8. Appreciation of beautiful things aids in making life happier.

9. The practical advantages of freeways do not offset the detrimental effects on our visual environment.

10. I see no reason for the government to spend money on esthetic objects and activities.

11. People should be allowed to pick wildflowers in order to enhance the beauty of their lives.

12. The educational curriculum should consist of subject matter to be learned and skills to be acquired.

13. Improved construction of freeways and automobiles makes driving skills less necessary today than five years ago.

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[1] In the original form, five boxes were shown below each statement.
[2] In the original form, the word *esthetic* was spelled *aesthetic* throughout.

14. The laws against littering should be more strictly enforced.

15. Schools should not be permitted to use school time for instruction in safe driving skills.

16. I sometimes go driving or walking in the countryside or state parks, but my reasons are usually other than those of esthetic pleasure.

17. Where the countryside or forests are green one need not worry about discarding cigarette butts or used matches on the ground.

18. Forest fire danger in California open country is highly overrated.

19. Drivers who disregard traffic regulations should be punished even when they have not caused damage or injury.

20. Leaving an occasional tin can in the woods is all right because it will rust out in the winter snows.

21. Fire prevention rules and regulations should be more strictly enforced.

22. One of the big difficulties with modern schools is that discipline is often sacrificed to the children's interests.

23. The curriculum should contain an orderly arrangement of subjects that represent the best of our cultural heritage.

24. "Smokey Bear" does a good job of alerting the public to fire dangers.

25. Deciphering messages carved in trees and park benches is intriguing.

26. People should be required to obtain fire permits much on the same basis as drivers' licenses.

27. The driver of a car should decide when it is safe to pass on curves.

28. The true view of education is so arranging learning that the child gradually builds up a store house of knowledge that he can use in the future.

29. Even though in an experienced camper's judgment it is perfectly safe to build a fire; he nevertheless should be punished if he does so in a prohibited area.

30. Progress in achieving insect-free fruits and vegetables should take precedence over concern with the balance of nature.

31. Because "things just happen" one should not be concerned with the prevention of fires and other accidents.

32. When litter cans are not provided, garbage should be left where it is fully exposed to the irradiating effects of sunlight.

33. Rangers should have more important things to do than going around checking on the fire behavior of forest visitors.

34. Our schools encourage an individual to think for himself.

35. The present emphasis on the enforcement of traffic rules should be reduced.

36. Fire prevention literature is a waste of taxpayers' money.

37. You don't have to worry about the woods because Mother Nature will always take care of the trees.

38. Observing fire prevention rules is my personal responsibility.

39. School training is of little help in meeting the problems of real life.

40. Esthetic education is nonsense.

41. A neat and tidy car is more important than a few pieces of paper on the freeway.

42. Schools should not be permitted to use school time for instruction in forest fire prevention.

43. I like beautiful things because they give me genuine pleasure.

44. Education in artistic things is a waste of public funds.

45. Education and educational institutions must be sources of new social ideas; education must be a social program undergoing continual reconstruction.

46. High school courses are too impractical.

47. Practical considerations should come first, beauty second.

48. A high school education makes a man a better citizen.

ADJECTIVE CHECK LIST

Check each of the adjectives which you feel is descriptive of your feeling, state or mood at this moment. Use a double check (✓✓) to the left of the number of the adjective if the adjective definitely applies, a single check (✓) if it slightly or possibly applies, leave it blank if it seems not to apply or if you cannot decide, and cross the adjective out with a straight line if it definitely does not apply. Leave less than half of the adjectives blank (i.e., 37 or less).

☐☐	1. [illegible]	☐☐	26. light-headed	☐☐	51. uneasy
☐☐	2. neutral	☐☐	27. capable	☐☐	52. jittery
☐☐	3. serious	☐☐	28. confused	☐☐	53. upset
☐☐	4. [illegible]	☐☐	29. cautious	☐☐	54. threatened
☐☐	5. kindly	☐☐	30. headache	☐☐	55. agreeable
☐☐	6. witty	☐☐	31. amused	☐☐	56. disinterested
☐☐	7. [illegible]	☐☐	32. fearful	☐☐	57. industrious
☐☐	8. worried	☐☐	33. restless	☐☐	58. keyed-up
☐☐	9. [illegible]	☐☐	34. annoyed	☐☐	59. sympathetic
☐☐	10. helpful	☐☐	35. blue	☐☐	60. powerful
☐☐	11. friendly	☐☐	36. goodnatured	☐☐	61. warm-hearted
☐☐	12. attentive	☐☐	37. intoxicated	☐☐	62. tense
☐☐	13. scared	☐☐	38. doubtful	☐☐	63. frightened
☐☐	14. quiet	☐☐	39. nervous	☐☐	64. calm
☐☐	15. [illegible]	☐☐	40. startled	☐☐	65. disturbed
☐☐	16. dizzy	☐☐	41. suspicious	☐☐	66. emotional
☐☐	17. tired	☐☐	42. shocked	☐☐	67. anxious
☐☐	18. reserved	☐☐	43. easygoing	☐☐	68. optimistic
☐☐	19. [illegible]	☐☐	44. contented	☐☐	69. critical
☐☐	20. regretful	☐☐	45. defiant	☐☐	70. obliging
☐☐	21. [illegible]	☐☐	46. cheerful	☐☐	71. peaceful
☐☐	22. cooperative	☐☐	47. drowsy	☐☐	72. sexy
☐☐	23. dubious	☐☐	48. horrified	☐☐	73. elated
☐☐	24. solemn	☐☐	49. apprehensive	☐☐	74. responsive
☐☐	25. alarmed	☐☐	50. hopeful	☐☐	75. excited

AFTER QUESTIONNAIRE

Directions: Choose only one answer for each question by marking an X in the box (as follows: [X]) after that statement which you think is the best answer, or which best describes your feelings regarding the initial statement.

PART I. Re: "T.V." Film Spot

(1) Which of the following best describes how you felt while viewing the film?

- Alarmed ☐ 1
- Somewhat troubled or anxious ☐ 2
- Neutral or indifferent ☐ 3
- Contented and/or hopeful ☐ 4
- Elated ☐ 5

(2) Did you feel that the message of the film was generally hopeful, neutral, or generally not hopeful about solving the man-caused forest fire problem?

- Generally hopeful ☐ 1
- Generally neutral ☐ 2
- Generally not hopeful ☐ 3

(3) Did you feel that the scenes portrayed were generally very pleasant, pleasant, unpleasant, or very unpleasant?

- Very pleasant ☐ 1
- Pleasant ☐ 2
- Unpleasant ☐ 3
- Very unpleasant ☐ 4

(4) Which of the following statements most accurately describes the message of the film?

- Forests will continue to be destroyed if people are not careful with fire ☐ 1
- Forests will continue to grow if people are careful with fire ☐ 2
- Forests will grow or be destroyed, depending on people's care with fire ☐ 3
- The film I saw was not about forests ☐ 4

(5) How interesting was this film to you?

- Very interesting ☐ 1
- Somewhat interesting ☐ 2
- Not very interesting ☐ 3
- Not at all interesting ☐ 4

PART II. Forest and Wildland Experience

(Note: By wildland areas we mean uncultivated areas covered with brush, grass, or trees.)

(6) Did you visit (i.e. drive through, picnic, camp, hike, swim, boat, hunt, fish, or etc.) in any forest or other wildland areas during the past year?

- No ☐ 1
- Yes ☐ 2

(7) Did you live or work in any forest or other wildland areas during the past year?

- No ☐ 1
- Yes ☐ 2

(8) All in all, how often would you say you have been in forest and wildland areas during the past year?

- Not at all ☐ 1
- 1 or 2 times ☐ 2
- 3 to 5 times ☐ 3
- 6 to 10 times ☐ 4
- 11 or more times ☐ 5

(9) In areas where campfire permits are required, they are required for the use of: (Check only one answer)

- Gasoline or propane type campstoves ☐
- Fire grates and charcoal burners ☐
- Open campfires ☐
- All of these ☐
- Do not know ☐

(10) Where the countryside or forests are green, one need not worry about discarding cigarette butts and used matches on the ground.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(11) Forest fire danger in California open country is highly overrated.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(12) The surest way to put out a campfire, assuming all these methods are available, is to: (Check only one answer)

- Pour water on it ☐
- Completely cover with dirt ☐
- Pour water on it and completely cover with dirt ☐
- Pour water on it and stir thoroughly ☐
- Spread out the embers and let it burn itself out ☐
- Do not know ☐

(13) Observing fire prevention rules is my personal responsibility.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(14) Rangers should have much more important things to do than going around checking on the fire behavior of forest visitors.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(15) If you drive your car off the road in dry grass areas:

- Exhaust sparks can start a fire ☐
- Sparks made by contact of metal parts of the car with rocks can set fires ☐
- Both 1 and 2 are correct ☐
- Neither 1 or 2 are correct ☐
- Do not know ☐

(16) "Smokey Bear" does a good job of alerting the public to fire dangers.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(17) Schools should not be permitted to use school time for instruction in forest fire prevention.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(18) Have you ever observed a wildland fire close at hand?

- No ☐ 1
- Yes ☐ 2

(19) Fire prevention literature is a waste of taxpayers' money.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(20) Even though in an experienced camper's judgment it is perfectly safe to build a fire; he nevertheless should be punished if he does so in a prohibited area.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(21) Green trees and shrubs of California:

- Are very difficult to burn ☐
- Will not burn at all ☐
- Will catch fire and burn very rapidly ☐
- Will burn only in hot summer months ☐
- Do not know ☐

(22) Because "things just happen" one should not be concerned with the prevention of fires and other accidents.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(23) People should be required to obtain fire permits much on the same basis as drivers' licenses.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

(24) Fire prevention rules and regulations should be more strictly enforced.

- Strongly agree ☐
- Agree ☐
- Undecided ☐
- Disagree ☐
- Strongly disagree ☐

PART III: Background Information

(25) Do you live: (Check only one answer)

- In a city ☐ 1
- In a suburb ☐ 2
- In a small town ☐ 3
- On a farm ☐ 4
- In the open country, but not on a farm ☐ 5

(26) Was your previous residence: (Check only one answer)

- In a city ☐ 1
- In a suburb ☐ 2
- In a small town ☐ 3
- On a farm ☐ 4
- In the open country, but not on a farm ☐ 5
- I have never moved ☐ 6

(27) Please check the highest level of education you have completed.

- Some grade school ☐ 1
- Completed grade school (grades 1-8) ☐ 2
- Some high school ☐ 3
- Completed high school (grades 9-12) ☐ 4
- 1 to 4 years of college ☐ 5
- Completed college ☐ 6
- Post graduate work ☐ 7

(28) Please check the age category you represent.

10 or under ☐ 1
11 - 13 years ☐ 2
14 - 20 years ☐ 3
21 - 24 years ☐ 4
25 - 34 years ☐ 5
35 - 49 years ☐ 6
50 - 64 years ☐ 7
65 and above ☐ 8

(29) Were you fully employed (30+hours/week) for the entire past year, or did you work part-time or just part of the year?

Fully employed ☐ 1
Part-time or just part of year ☐ 2
No work at all:retired or disabled ☐ 3
No work at all:student ☐ 4
No work at all:housewife ☐ 5
No work at all:unemployed ☐ 6
No work at all:other (specify below) ☐ 7

_____

(30) Are you married; widowed, divorced, separated; or single (never married)?

Married ☐ 1
Widowed, divorced, separated ☐ 2
Single (never married) ☐ 3

(31) Sex:

Male ☐ 1
Female ☐ 2

PACIFIC SOUTHWEST
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OREST SERVICE
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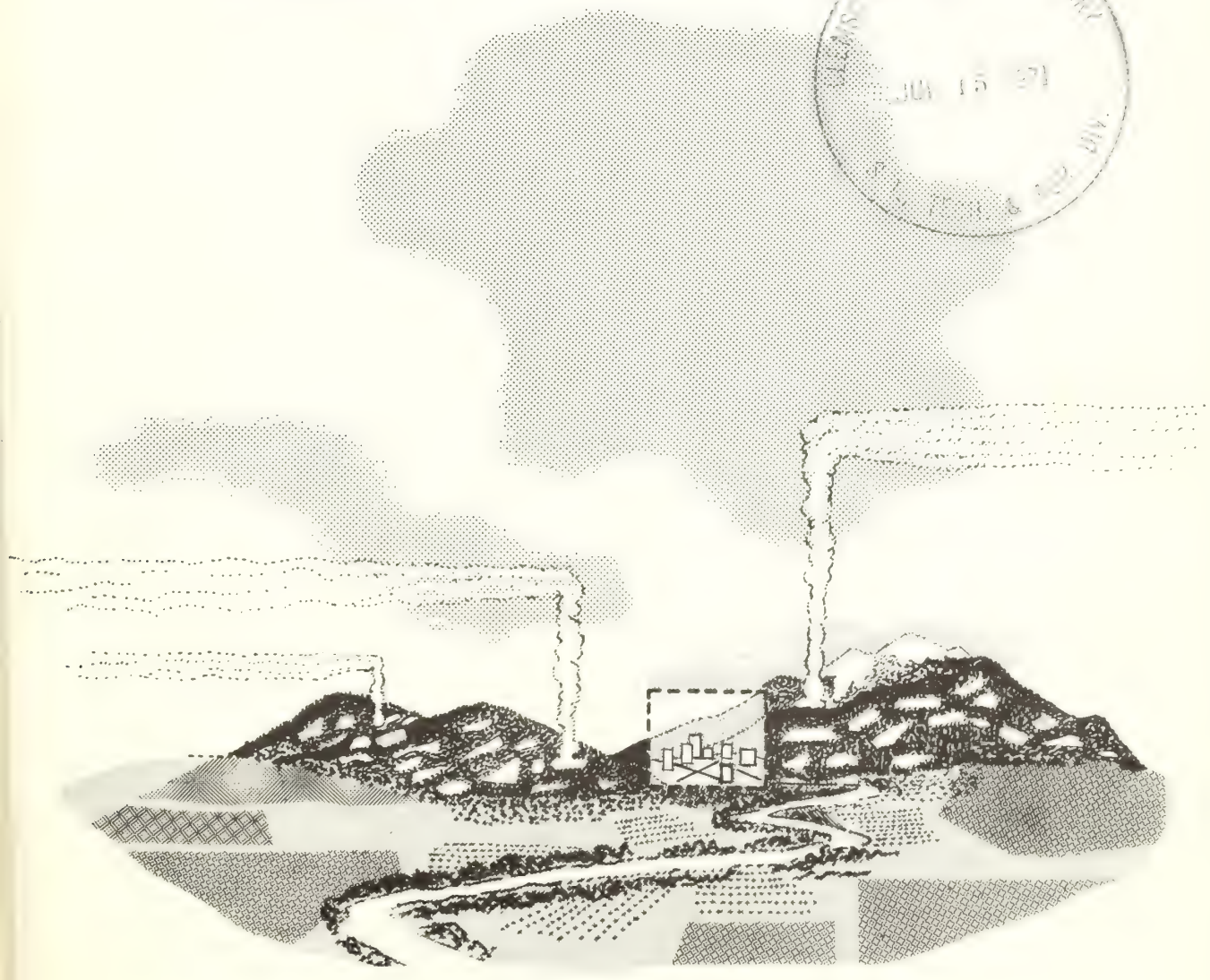
O. BOX 245, BERKELEY, CALIFORNIA 94701

POTENTIAL IMPACT OF AIR QUALITY RESTRICTIONS ON LOGGING RESIDUE BURNING

Owen P. Cramer

James N. Westwood

JUN 15 '71



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The Authors

OWEN P. CRAMER, a meteorologist, is doing research on Pacific Northwest weather conditions important to protecting forests from fire. Assigned to the Station's fire meteorology studies, he is headquartered in Portland, Oregon. He earned a forestry degree at Oregon State University (1941) and received meteorological training at the University of California, Los Angeles (1943). A former fire-weather forecaster, he has been in fire meteorology research since 1949, and with the Pacific Southwest Station staff since 1965. **JAMES N. WESTWOOD**, formerly a meteorological technician with fire meteorology studies at Portland, is now on active duty in the United States Navy. He holds a bachelor's degree in history from Portland State University (1967), and joined the Pacific Southwest Station staff in 1965.

Among a forest manager's many responsibilities is the reduction of fire hazard. In the Pacific Northwest, the greatest fire hazard is logging slash—the burnable material remaining after a forest crop is harvested. Where the hazard is great enough to require abatement, the usual method and often the only feasible one is judicious application of fire. But this job of burning has exacting requirements:

- The fuels must be dry enough to burn, but they must not be so dry that the fire will bake the soil severely or become difficult to control. Deep drying should be limited to lessen the chance of holdover fire in roots.
- The fuel or forest on the surrounding area must be damp enough to resist ignition from flying embers.
- Winds must be light so that the fire can be easily controlled.
- Forecasts of weather after burning must not indicate a combination of wind and humidity that would cause spread from wind-blown embers.

These requirements oblige foresters to consider only certain times of year suitable for burning. Because of the normal variation between years, in some years there may not be enough days with the ideal burning conditions, at least by some standards. When additional weather requirements are added to keep slash smoke out of populated areas, then the difficulty is intensified. The question immediately arises—if smoke dispersion limitations are imposed, will there be enough days with the right weather conditions to permit the burning job to be done, particularly during a year when burning conditions are unfavorable?

This paper provides at least a partial answer to that question, based on analysis of two seasons in western Oregon when excessive dryness would have limited the number of burning days.

BURNING AND AIR POLLUTION

What is the magnitude of this smoke source and why is it important? In recent years, some 90,000 acres of slash have been burned annually in western Oregon. This amount has been decreasing and will continue to decrease as utilization improves and as the total cut includes progressively less old-growth with its extremely high proportion of unusable rotten wood. But some old-growth will be cut until about the year 2020. By then, all cutting will be in younger managed forests in which the considerably lighter slash may require removal by fire only in special situations. In the meantime, commercial forest land must be quickly returned to production of a new crop. The soil must be accessible for natural reseeding or planting. Severe competition from brush must be controlled for several years. The fire hazard must be reduced to the point where protection of a young forest from fire becomes practical. These jobs can be accomplished by burning—and often only by burning.

State and regional air pollution control groups have been increasingly vocal in objecting to the large quantities of smoke produced by slash burning. Most objectionable is smoke that reaches the lower layers of air in populated areas, adding to the already more than ample load routinely placed there by urban and industrial sources. As an occasional component of polluted air, slash smoke is, by association, also blamed for the usually mentioned undesirable characteristics of polluted air—soiling, corrosion, health effects, visibility reduction, and photochemical smog formation. The absence of concrete evidence of these effects from slash smoke, except for visibility reduction, detracts very little from the increasing demands that slash smoke be controlled.

This trend is further accelerated by the air quality control agencies. They regard any visible plume as contributing to pollution. And they are basically opposed to open burning. Slash burning is open

burning and certainly produces substantial plumes of smoke. The fact that these plumes are predominantly away from populated areas and at high elevations brings the additional criticism that by reducing visibility of and in mountain areas under some weather conditions, slash smoke may be damaging to the tourist industry. There is no question that the practice of burning logging slash is under real pressure from the various proponents of clean air.

Additional pressures can be expected. In 1969, the Oregon State Legislature directed the State Forester and the Environmental Quality Commission to set up procedures for control of pollution from slash smoke. The National Air Pollution Administration (1969) has issued guidelines to State agencies for preparing air quality standards for particulate matter. Slash burning produces slightly less than 10 pounds of particulate (smoke size particles) per ton of slash burned (Fritschen, *et al.* 1970; Darley 1969). According to the NAPCA, particulate, in association with sulfur dioxide, is corrosive to iron and steel when the mean annual concentration exceeds 60 micrograms per cubic meter. This concentration is considered equivalent to a reduction of visibility to about 13 miles. Also in association with sulfur dioxide, particulate has adverse health effects at concentrations equivalent to a reduction in the visual range to about 10 miles. Sulfur dioxide is not produced in slash smoke, but slash smoke particulate would not be welcomed where sulfur dioxide is produced. Because of corrosive and health effects listed for particulate, we may expect increasing objection to slash smoke for other than esthetic reasons.

Slash smoke is likely to get additional attention as a source of hydrocarbons. Slash burning liberates about 12 pounds of hydrocarbons per ton of slash consumed. This amount compares with 130 pounds in auto exhaust per ton of gasoline burned. Though photochemical smog has not as yet been produced in the laboratory from wood smoke as it has from auto exhaust, some of the same reactive hydrocarbons have been shown to be present, as have slight amounts of photochemically active nitrogen oxides (Darley, *et al.* 1966).

With increasing indictment of slash smoke, justified or not, the popular and legal pressure to keep concentrations of slash smoke out of the urban areas at least may be expected to mount. Strict limiting of burning to periods when weather conditions will assure that smoke does not enter what we might call *smoke-sensitive areas* may be the answer. A smoke-sensitive area is one in which smoke from sources outside it is intolerable, owing to heavy population, existing air pollution, or intensive recreational or tourist use. This restriction would amount to limiting the emission rate to the dispersion potential. With slash burning this is possible because: (a) Most commercial timber areas in the Pacific Northwest are remote from and at a significantly higher elevation than smoke-sensitive areas; (b) slash fires produce hot, high-rising convective plumes; and (c) each burn lasts only a few hours and can be delayed until predicted burning and dispersion conditions are right for the particular area.

Considerable adjustment of current burning practice may be required. Where suitable days for burning have always been at a premium, additional restrictions would raise the questions: How much burning can be done under the additional restrictions necessary for maintaining air quality? Will it be enough to prevent the extreme pollution conditions and wildland damage caused by large forest fires, precisely what hazard-reducing slash fires are designed to prevent? And will it be enough to accomplish other forestry jobs such as necessary control of brush to secure forest regeneration?

METHOD

The study procedure consisted of estimating the number of days when broadcast burning could be done and the theoretical acreage that could be burned during two similar burning seasons on five hypothetical administrative units the size of a U.S. Forest Service Ranger District. The slash burning season was assumed to be May 1 through October 31. The years chosen, 1966 and 1967, were both unusually dry, and were intentionally selected to represent poor burning seasons.

The Willamette Valley is assumed to be a smoke-sensitive area to an elevation of 2,500 feet above mean sea level. The area consists of the portion of the Valley, including population centers, ending at the foothills of the Coast (west) and Cascade (east) Ranges, and extending vertically to 2,500 feet elevation. Lateral boundaries correspond to weather zone 20. The five hypothetical administrative areas for which suitability of burning conditions was judged are on either side of the Valley near Salem and at

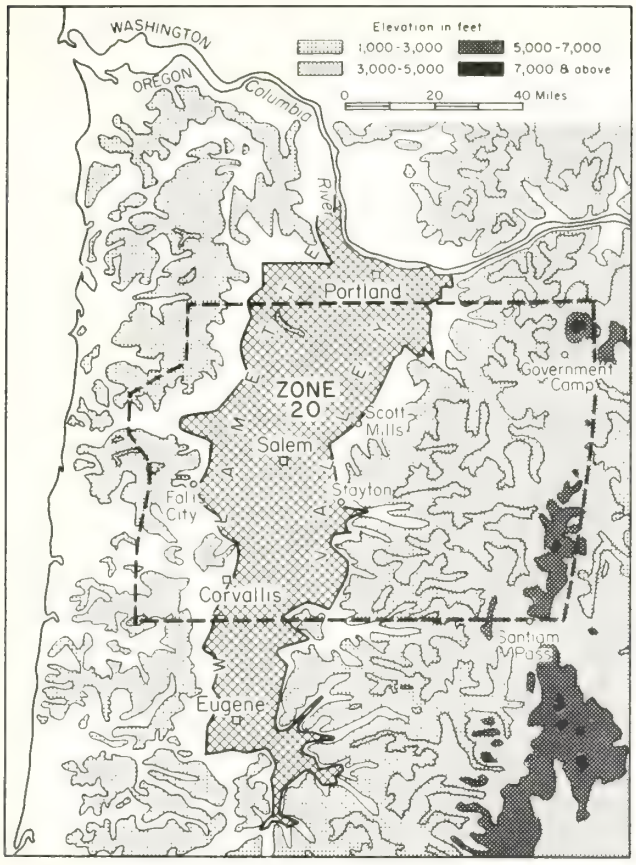

Figure 1—*The study area (defined by dashed line) and the smoke-sensitive area, weather zone 20, in Northwest Oregon.*

several elevations representing the forest areas on the east half of the Coast Ranges and west half of the Cascade Range *(figs. 1,2)*.

Although in actual practice the weather and fuel conditions sampled would vary appreciably from place to place, for this study, all conditions were determined from surface and upper air weather observations made at the Salem U.S. Weather Bureau Airport Station (see Appendix).

Specifications

The count of days available for broadcast burning of logging slash was based on specifications established for this study in the categories of (1) fuel condition, (2) burning weather, and (3) smoke dispersion conditions.

1. *Fuel condition*—Fuels must have dried sufficiently both to carry the fire over the area and to consume enough of the fuel to accomplish the hazard reduction or brush removal objective. Conversely, fuels must not be so dry as to make confinement of the fire difficult or to produce such a hot fire as to damage the soil.

Favorable conditions were as follows: Adjusted fuel moisture between 8 and 18.5 in the spring, and 8 and 25.5 in summer and fall at the Salem airport at 1600 P.s.t. (National Fire Danger Rating System). Fuel moisture limits are adopted from Morris (1966). Buildup, representing deeper drying in heavier fuels and duff, between 25 and 75 in spring and summer,

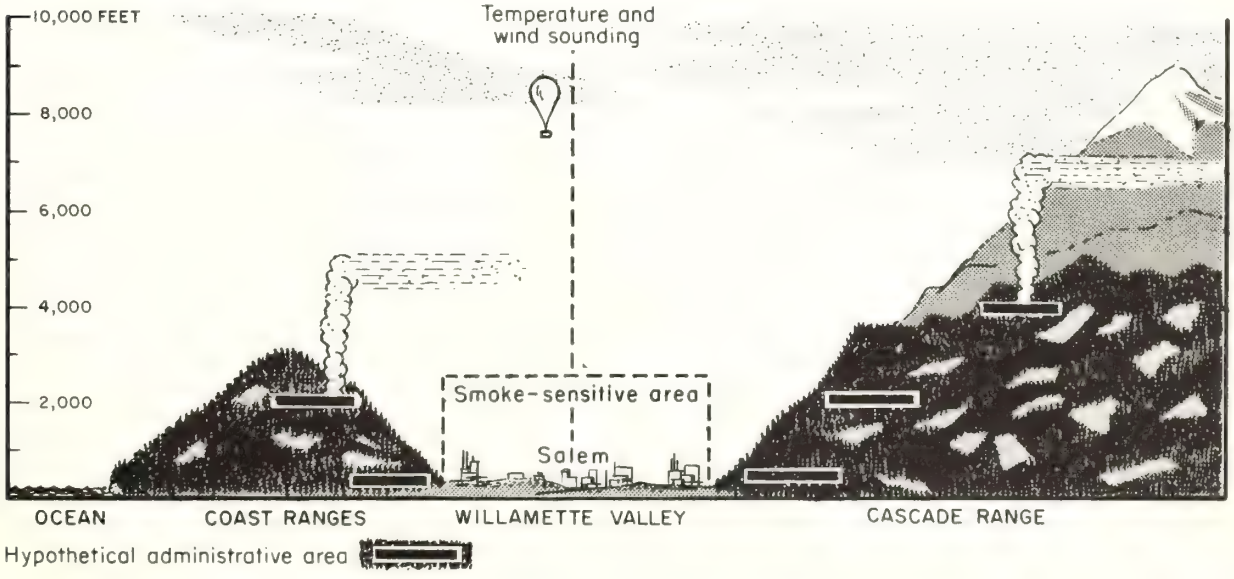

Figure 2—*Schematic cross section shows east-west and vertical arrangement of hypothetical administrative areas and smoke-sensitive area.*

and 0 to 75 in fall at Salem. After September 1, 1 inch of rain must have fallen within the preceding 10 days at Salem. This specification assumes considerably greater precipitation amounts in mountain areas and is intended to minimize soil damage by hard burning after a summer drought.

2. *Burning weather*—Conditions must be such that fire intensity would permit easy control with limited rate of spread and no trouble from spotting on the day of the burn. For study purposes, actual weather the following day was required to be such that there was no danger of spot fires from embers blown from remnant fires. Limits were: Maximum allowable wind, 10 m.p.h. (1000 to 1600 P.s.t.); burning index not over 21 on burn day or following day.

3. *Dispersion conditions*—Smoke in objectionable concentration must be kept out of the populated central portion of the Willamette Valley, which was designated a smoke-sensitive area. Several conditions were considered: (1) Direction of winds acting on the smoke from base to venting height—wind directions carrying smoke toward the Valley were differentiated from directions carrying smoke away from the Valley. And to allow for some variation in wind and smoke behavior, winds parallel to the Valley were considered blowing toward it. (2) Speed of wind acting on the smoke—this wind must be of sufficient force for classification of wind as blowing from a definite direction and not as variable or calm. (3) Stability conditions that limit the smoke rise over slash area; i.e., the dispersion level, which may vary with the terrain. The dispersion level is the height at which smoke loses buoyancy and moves with the prevailing motion of the surrounding air. In this study, dispersion level is considered to be at mixing level over the slash area. Mixing level is the top of the layer within which vertical mixing may be expected during midday as a result of heating at the ground (see Appendix). (4) Stability conditions over the Valley that would limit smoke descent into the Valley.

Classification

Each day on which fuel and burning weather conditions were determined to be favorable was classified for smoke dispersion characteristics on the basis of the wind and temperature profiles indicated by the 1600 P.s.t. rawinsonde observation at Salem. Mixing levels on both sides of the Valley were determined by assuming dry adiabatic ascent from the maximum temperatures at representative surface stations to intersection with the Salem temperature curve (Miller 1967; Holzworth 1967). Through use of data from such stations as Fall City, Stayton, Scotts Mills, and Government Camp, account was taken of any temperature gradients in the airmass from west (Coast Ranges) to east (Cascade Range) and of any

Table 1—*Restrictions of burning imposed by midafternoon dispersion conditions, Willamette Valley, Oregon*

Daily burning quota[1]	Midafternoon dispersion conditions		
	Direction of wind on smoke plume	Dispersion level (ft.) of smoke plume over Valley	Dispersion conditions
1. Unlimited burn (240 acres per day average)	Away from smoke-sensitive area at 9 m.p.h. or greater	Any level	No requirement
2. Slight limitation (160 acres per day)	Toward smoke-sensitive area[3] or less than 9 m.p.h. any direction	Above 5,000	Stable layer[2] over smoke-sensitive area and below dispersion level
3. Moderate limitation (120 acres per day)	Same as above	(a) Above 5,000 or (b) Above 2,500	(a) Deep mixing (b) Stable layer[2] over smoke-sensitive area and below dispersion level
4. Severe limitation (80 acres per day)	Same as above	2,500-5,000	Deep mixing
5. No burning	Same as above	Below 2,500	Any condition

[1]Applies to an administrative unit of ranger district size including 6 to 10 townships.
[2]See Appendix for method of determining existence of stable layer.
[3]Includes winds too light to depend on—in this study, less than 9 m.p.h.

greater heating over the mountains (see Appendix).

The burning restrictions imposed by smoke dispersion conditions in terms of the acreage of permissible burn assumed in this study for each condition is summarized in *table 1.* The 240 acres for an unrestricted day is not a quota but an estimate of an average amount. The assumed quotas would apply to an administrative area of Ranger District size, which may include 6 to 10 townships. The basic assumption is that emissions are controlled by limiting the acreage of burn according to dilution potential, vertical separation, and horizontal displacement of the smoke with respect to the smoke-sensitive area.

There is a distinct difference between these estimates of suitable burning days based on many assumptions and partial data, and the actual operational prediction and measurement of conditions influencing the suitability of burning. Only data readily available have been used and the method followed for the sample years is not intended as a model for predicting or determining by observation the suitability of burning conditions. We hope that the operational procedures will be based on considerably more complete weather and fuel data as well as on a more precise statement of burn requirements for each area.

RESULTS

In the first phase of the procedure, potential burning days were identified on the basis of suitable fuel moisture and favorable existing and following burning weather. In the two 6-month seasons examined, a total of 89 days *(table 2)* qualified as potential burning days on this basis. These days were about equally divided between the 2 years. Nearly all were in spring or fall, when 40 to 45 percent of the days

Table 2–*Potential burning days and summary of conditions precluding burning for areas east and west of the Willamette Valley, Oregon, May 1-Oct. 31, 1966 and 1967*

Month and year	Number of suitable days	Number of days unsuitable due to:					
		Condition of slash			Burning weather[1]		
		Too wet	Too dry	Buildup too high	Burning index too high	Burning index too high next day	Too windy
May 1966	15	2	0	0	5	4	5
May 1967	16	8	0	0	2	1	4
June 1966	2	0	14	12	0	1	1
June 1967	11	0	6	3	5	4	1
July 1966	5	1	13	7	2	2	1
July 1967	0	0	30	1	0	0	0
Aug. 1966	0	0	28	3	0	0	0
Aug. 1967	0	0	31	0	0	0	0
Sept. 1966	8	0	16	0	1	1	4
Sept. 1967	0	0	30	0	0	0	0
Oct. 1966	16	3	1	0	4	2	5
Oct. 1967	16	2	2	0	0	0	11
Total	89	16	171	26	19	15	32

[1]If more than one burning weather criterion applies, the day is listed under the first applicable heading, reading from left to right.

offered good burning conditions. Only 7 days in the 2 years qualified from the June 16 to September 15 period. Greatest deterrents in May were high fuel moistures and too much wind, with about the same frequency. From June through September, most days were unsuitable because of excessive dryness. In October, the greatest problem was too much wind. These fire-weather and fuel moisture conditions were assumed to be similar at all elevations. Effect of any residual snowpack at the higher elevations was ignored.

The 89 potential burning days were then classified according to weather conditions affecting dispersion of smoke. Predominance of winds from a westerly quadrant permitted the Coast Ranges only 14 unlimited burning days at the low elevation compared with 45 such days for the low level in the Cascades on the east side of the Willamette Valley *(table 3)*.

On only 15 of the 89 potential burning days was burning at the 200-foot elevation prohibited on one or both sides of the Valley (11 days each side) by a combination of low dispersion level and wind not

Table 3—*Smoke dispersion conditions affecting burning on the 89 suitable days, by portion of season, 1966-67 combined, for representative elevations east and west sides of the Willamette Valley, Oregon*

Area, elevation and date[1]	Number of days with indicated daily burning quota and midafternoon dispersion conditions[2]					
	(1) Unlimited burn (240 acres average)	(2) Slight limitation (160 acres)	(3a) Moderate limitation (120 acres)	(3b) Moderate limitation (120 acres)	(4) Severe limitation (80 acres)	(5) No burning
West, 200 ft.						
May 1-31	2	1	2	14	11	1
June 1-July 15	4	0	0	6	8	0
Sept. 16-Oct. 31	8	0	3	6	13	10
Total	14	1	5	26	32	11
West, 2,000 ft.						
May 1-31	3	2	1	21	4	0
June 1-July 15	3	0	0	9	6	0
Sept. 16-Oct. 31	5	7	12	6	9	1
Total	11	9	13	36	19	1
East, 200 ft.						
May 1-31	17	0	2	3	8	1
June 1-July 15	8	1	0	6	3	0
Sept. 16-Oct. 31	20	0	2	2	6	10
Total	45	1	4	11	17	11
East, 2,000 ft.						
May 1-31	21	1	2	3	4	0
June 1-July 15	9	0	0	5	5	0
Sept. 16-Oct. 31	25	0	8	3	4	0
Total	55	1	10	11	12	0
East, 4,000 ft.[3]						
May 1-31	27	1	2	1	0	0
June 1-July 15	8	1	1	3	5	0
Sept. 16-Oct. 31	28	2	7	0	3	0
Total	63	4	10	4	8	0

[1]Favorable burning days, by portion of season, for 2-year period: May (31 days); June-July 15 (18 days); September 16-October 31 (40 days). No favorable burning days in 1966 and 1967 from July 16 to September 15.
[2]See table 1 for descriptions of quotas and conditions in each numbered classification.
[3]Dispersion level elevation classes are 4,000-7,000 ft. (3b and 4) and over 7,000 ft. (2 and 3a).

Table 4—*Poor dispersion and low visibility during 89 potential burning days*[1] *at low elevation, Willamette Valley, Oregon*

Dispersion conditions	Potential burning days[1]		
	Low visibility days[2]	Other days	Total days
Dispersion level below 2,500 feet:[3]			
West winds (no burning west of Valley)	2	2	4
East winds (no burning east of Valley)	1	3	4
Indeterminate winds (no burning)	4	3	7
Total	7	8	[4]15
Dispersion level above 2,500 feet:[5]			
All wind conditions combined	2	72	74
Total	9	80	89

[1]Fuel and burning weather conditions satisfactory.
[2]Days with average visibility of less than 7 miles at Salem airport; all after September 15.
[3]Applies only to burning at 200-foot elevation. Midafternoon dispersion condition 5 (see table 1).
[4]Includes one day in May; all others after September 15.
[5]Midafternoon dispersion conditions 1-4 (see table 1).

blowing away from the Valley *(table 4)*. All but one of these days occurred after September 15. Also included in the low dispersion level group were 7 potential burning days when visibility in the sensitive area averaged below 7 miles. Two other low-visibility days in October had dispersion levels near 3,000 feet. Burning at the 2,000-foot level was prohibited by a low dispersion level on only 1 day and then on one side of the Valley. Incidentally, the mean mixing level in October on potential burning days averaged 1,000 to 2,000 feet lower than May mixing levels over each burning elevation.

On all the remaining 78 potential burning days, some burning could be done in the low elevation areas. West of the Valley, however, dispersion conditions imposed severe restrictions on burning on 32 days and moderate limitations on another 31 days. Even at the 2,000-foot level in the Coast Ranges, moderate restrictions on burning were necessary on 49 days, and there were only 11 days of unrestricted burning compared with the 14 unrestricted burning days at the lower elevation.

The relative importance of each type of day becomes apparent from the total acreages of potential burning under each heading *(table 5)*. In the Coast Ranges, because of the scarcity of offshore winds during the burning season, lesser acreages must be burned on the more frequent days with sufficiently high mixing levels in air moving toward the Valley. The 2,000-foot level in the Coast Ranges has a higher mixing level, particularly during the fall. This permitted hypothetical burning of 1,650 acres more in the 2-year test period than was burned at low elevation in the Coast Ranges.

In forest areas on the east side of the Willamette Valley at all elevations, there are more days than in Coast Ranges forests when slash may be burned without contributing smoke to the Willamette Valley. The effect of the predominating westerly winds throughout the 6-month season studied shows plainly in *table 3*. Even at the Valley levels, on 45 of the available 78 days, windflow was generally away from the Valley. The difference increases with elevation, so that 55 days were available for unlimited burning at 2,000 feet and 63 days at 4,000 feet. The advantage of the Cascade location and of elevation is reflected in potential acreage burned *(table 5)*. At the 2,000-foot level, the Cascade advantage over the Coast Ranges amounts to 5,000 acres for the two test seasons. The altitude advantage on the Cascade side totals more than 4,000 acres between the 200- and 4,000-foot elevations, clearly showing the effect of more favorable dispersion conditions at higher elevations.

Table 5—*Potential acreage burn totals,*[1] *May1-October 31, 1966 and 1967 combined, at representative elevations, east and west sides of the Willamette Valley, Oregon for hypothetical administrative areas of ranger district size*

Site and elevation	(1)[2] Unlimited burn (240 acres/day average)	(2) Slight limitation (160 acres/day)	(3) Moderate limitation (120 acres/day)	(4) Severe limitation (80 acres/day)	Two-year total (acres)
West:					
200 ft.	3,360	160	3,720	2,560	9,800
2,000 ft.	2,640	1,440	5,880	1,520	11,480
East:					
200 ft.	10,800	160	1,800	1,360	14,120
2,000 ft.	13,200	160	2,520	960	16,840
4,000 ft.	15,120	2,240	1,440	0	18,800

[1]Maximum allowable burn each day is assumed.
[2]See table 1 for description of dispersion conditions in each numbered classification.

DISCUSSION

Application of Study

The significance of the potential burn acreages *(table 5)* lies in how they compare with the acreage of slash to be abated on any given district in the study area in any 2-year period. A forest manager faced with the prospect of limiting slash smoke production should be able to predict about how much slash he will be able to burn in a normal year, using all opportunities. If the potential acreage is too low when only fall burning is assumed, he should consider the potential burn acreage in spring. If the total is still short of the acreage of slash created, important changes in operations or policy may be necessary:

1. Abate slash by methods other than burning, including changes in logging practice.

2. Accept responsibility for protecting greater acreage of unabated slash.

3. Burn under more severe or otherwise limiting weather conditions, accepting the increased costs of preparation, burning, and mopup that would accompany an all-around more intensive burning operation.

4. Reduce the annual cut until an acceptable balance can be achieved between hazard created, hazard protected, and hazard abated.

All these alternatives require planning and implementation time. A study such as this helps the manager evaluate the need for revision of his slash disposal strategy.

Before applying the results of this study or starting a similar study for another area, the manager might consider some pertinent details. Though other limits of restrictions to burning might have produced slightly different results, some of the basic conditions are illustrated by this 2-year sample of a May-October season. A longer season may be desirable. Additional weather favorable for both burning and smoke dispersal is likely in many years both before and after this burning season. Note that suitable burning days occurred in both study years on May 1 and October 31. This might be of particular importance for Coast Ranges burning, which would be favored by the greater frequency of offshore flow in earlier spring and later fall periods (Cramer 1957).

The frequency of favorable burning weather in the 2 study years is probably less than normal as both years were very dry. In 1966, the Siuslaw National Forest, on the west slope of the Coast Ranges, reported its driest fire season since 1952. And at Eugene, the April-August rainfall was the lowest ever recorded. Similarly, the 1967 season was the warmest and driest of record in western Oregon. On the damper west slope of the Coast Ranges, not included in this study, these dry years may have been more favorable for slash burning than damper years when adequately dry days are at a premium.

It would seem that many burning days are available in spring and early summer, on a basis of

burning conditions and smoke dispersal conditions alone. However, these are not the only considerations that determine the time of year suitable for burning. The extra risk of holdover fires in large and underground fuels from spring and summer burns has been the primary reason that spring burning is limited. Holdover fire potential would have to be taken into account for otherwise unrestricted burning days noted in the May 1-July 15 period, particularly east of the Willamette Valley. Some burns would not be considered and others would require thorough mopup and patrol. Immediately west of the Coast Ranges area considered in this study, the Siuslaw National Forest has practiced spring and summer burning successfully for many years. But specifically because of the risk of holdover fire, this has not been the practice in the Cascades where drier summer fuel and weather conditions normally prevail. This restriction would be less applicable in other regions where the summer is not normally a drought period as it is in the Pacific Northwest.

Limitations of Study

This study obviously cannot cover all possible variations in requirements for burning conditions and air quality restrictions. Only a single set of simplified conditions has been used. Results should be interpreted only with awareness of attendant limitations.

The study model encompassing fuel moisture, burning weather, and air quality requirements has the following limitations:

1. Since the sample is limited to exceptionally dry years, we have no estimate of comparative frequency of favorable burning conditions during unusually wet years. Wetness may prove even more limiting than dryness in some areas.

2. Assumed limits of fuel moisture and fire danger for suitable burning days are not likely to apply to every slash situation. Presumably, the limits imply that conditions are favorable in some slash somewhere within the study areas. Limits were set after consultation with field foresters experienced in prescribed burning; however, there was not complete agreement. In actual practice, because of basically different climatic and fuel conditions, favorable limits for east slope Coast Ranges burns may be different from limits for west slope Cascade Range burns. Even greater differences may be expected between individual slash areas.

3. Burning conditions have been assumed not to change with altitude. In the Willamette Valley and adjoining mountain ranges, this would not necessarily be justified, primarily because of the fluctuating height and intensity of the marine inversion and contrast of airmass properties above and below. An assumption of no change with elevation is probably not too much in error, on the average. Actually, variations due to difference in aspect at one elevation probably exceed average differences due to elevation.

4. In this study, burn quotas for a given condition were assumed for a hypothetical administrative unit of a single elevation. In actual practice, burns must be made at many elevations. An ideal basis for quotas would be the amount of smoke, hence, acreage of burn, contributing to a particular air layer. But the differentiation of significant layers changes with the weather. Quotas could be set up currently for the existing layer structure on the basis of whether the smoke-receiving layer was mixed and in contact with the smoke-sensitive area or whether it remained in a stratum entirely above the sensitive area.

5. No allowance was made for hot convective columns that might push smoke well above the mixing height. Fires with this capability might very well be burned when lesser fires might not be desirable, or such fires might be ignited earlier in the day.

6. Possible nocturnal drainage of smoke from smoldering slash fire remnants within reach of a smoke-sensitive area may be more important than the primary plume. Downslope flow of smoke into low places would be most noticeable on windless nights with stable air. Such nights would be expected to follow days with light winds and clear skies. The amount of fire still in the smoldering stage when nocturnal drainage winds commence can be minimized by scheduling ignition early in the morning.

7. Increasing diffusion with distance between smoke source and smoke-sensitive area has not been taken into account. For individual fires, this may be an important factor, but if many adjacent administrative areas are all under similar guidance, the cumulative effect of smoke sources at various distances may tend to offset dilution effects unless timing is also considered. Actual spacing of burns by time and location to avoid reinforcing smoke plumes from fires upwind may be necessary.

8. Wind aloft over the burn site determines the extent of burn restriction. In some situations, error may have been introduced by assuming winds aloft over burn areas in the Coast and Cascade Ranges were represented by Salem upper wind observations.

9. A few days would have been assigned higher burning quotas if the data had permitted use of a lower speed for indeterminate wind direction, which

included all winds less than 9 m.p.h. A 5 m.p.h. threshold might be adequate.

10. Instability is not considered an impediment to burning. Experimental burning of slash areas under all summer weather conditions in western Montana, where instability is often more pronounced than over western Oregon, indicates this assumption is justified. This applies to the usually considered thermodynamic atmospheric stability, not to aerodynamic stability of flow around obstacles.

11. Potential burn acreages have been assigned on the basis of weather at 1600 P.s.t. Diurnal changes have not been taken into account. A day with wind toward a smoke-sensitive area, classified on the basis of 1600 P.s.t. dispersion conditions as deep mixing (3(a) or 4 in *table 1*), could often become a night with smoke *above a stable layer* (2 or 3b in *table 1*), allowing greater burn acreage at least at higher elevations. The possibility of additional burning at night in the higher areas was not evaluated.

12. Assumption of full use of every favorable burning period may not be realistic. Conflicting activities and burning bans on weekends may eliminate some opportunities. Another important variable is the accuracy of weather forecasts upon which scheduling of the burning would actually depend. Although accuracy of general forecasts may be high, the detailed structure of winds and stability required for control of slash smoke may be quite difficult to predict for mountain areas. The forecaster is now handicapped by an absence of upper air reports from mountain areas and even surface reports during early and late portions of an expanded burning season.

13. Greater acreages might be burned under "unlimited" burning conditions, for which an average figure of only 240 acres per day was assumed.

The burning conditions assumed have been for broadcast burning. Burning of large yarded piles of slash—an increasingly common practice—would involve a broader spectrum of favorable weather conditions. The piles could be burned in late fall and winter under wetter conditions when broadcast burning would be impossible. In drier weather, night burning might be favored. For yarded-pile burning favorable smoke dispersion weather may include precipitating cloud systems in which removal of slash combustion products from the atmosphere might be accelerated.

The range of conditions under which hazard reduction or other prescribed burning can be safely done can be further broadened by varying: (a) fuel preparation, (b) fireproofing beyond the fire perimeter, and (c) ignition procedures. The potential burning days under air quality restrictions, as determined here for exceedingly restricted conditions, should be considered a near minimum that might be significantly increased in actual practice.

SUMMARY

Cramer, Owen P., and James N. Westwood.
1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

Oxford: 332.3–436:(795):U628.53[+425.1].
Retrieval Terms: slash disposal; broadcast burning; air pollution; smoke abatement; Willamette Valley; Oregon.

The potential number of days for burning logging slash and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area in the Willamette Valley, western Oregon. The hypothetical areas were five administrative units the size of U.S. Forest Service Ranger Districts. The slash burning season was assumed to be May 1 to October 31. The years chosen for study—1966 and 1967—were both unusually dry, and were intentionally selected to represent poor burning seasons. The count of days available for burning was based on specifications set up in the study for the categories of (a) fuel conditions, (b) burning weather, and (c) smoke dispersion conditions.

The requirement of favorable smoke dispersal weather, in addition to the usual rather exacting requirements of favorable burning weather, greatly restricts the number of days when unlimited broadcast burning of slash may be done west of the

Willamette Valley. Though still substantial, the restriction is much less for burning east of the Valley, and decreases progressively for slash at 2,000 feet and 4,000 feet elevation. The greater restriction of Coast Ranges burning is the direct result of more frequent windflow from a westerly quadrant toward the Willamette Valley smoke-sensitive area.

If the burning season is expanded into spring, the theoretical number of burning days is nearly double the number available only in fall. The total of days classed as favorable for burning was probably well below normal because, in the test years, weather during the summer period was too severe for burning under the limits set. On the other hand, unusually wet years might provide even fewer burning opportunities.

A few additional burning days can be picked up in some years in March and April and again in November. Offshore flow is more frequent in these months, making them important to Coast Ranges burning.

Low mixing level or valley inversion conditions are a serious impediment to burning at low elevations only in fall. These conditions account for most of the low-visibility days. Dispersion from high-elevation sources is not affected except that smoke from higher sources is possibly prevented from descending to lower elevations.

In actual practice successful management of the smoke from prescribed burning depends fully on optimum use of specially tailored weather information. Of primary importance would be accurate, timely forecasts of upper wind and stability conditions over the mountain areas. Such forecasts would depend on current surface and upper air reports from mountain areas.

This study assumed broadcast burning of rather heavy slash in place, with normal precautions. With favorable burning days at a premium, other possible alternatives need to be further developed to broaden the range of conditions under which slash burning and other prescribed burning may be successfully accomplished. Faced with the prospect of increasing accumulations of slash if he continues business as usual in the face of limitations on smoke release, the forest manager may be forced into one or a combination of several alternatives: These might include redefining the material that must be removed in logging and changing the treatment of residual material. Other possibilities are more intensive burning during periods of less ideal weather with the necessary fuel preparation, special ignition techniques, fireproofing of the surrounding area, and aggressive mopup. But, if costs of both intensive burning and protection of increasing acreages of slash make these unacceptable alternatives, and clean logging is not feasible, there is still another possibility—reduce the acreage cut each year to a level at which the slash can be handled.

The impact of smoke control regulations may be great on some districts and slight on others, depending, of course, on normal local weather conditions and on the specific smoke control limitations imposed. After specific regulations have been adopted, it may be helpful to assess their effect on probable annual burn acreage by some such study as this one.

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APPENDIX: *Detailed Procedures*

Determination of mixing levels. Plotted daily afternoon radiosonde observations (raobs) from Salem were used as a basis. Daily temperature maximums for the stations listed below were taken from the Weather Bureau's Monthly Climatological Summaries for Oregon and plotted on a pseudo-adiabatic chart at appropriate pressure heights as shown below. Mixing levels were defined as the intersection of the potential temperature of the maximum temperature and the Salem raob curve. The pressure height thus found was converted to the nearest hundred-foot elevation by using the standard-atmosphere-based scale on the pseudoadiabatic chart. This means that on warm days the actual mixing level may have been 100-200 feet greater than that recorded for the study.

Stations used, and the pressure heights at which their daily maximums were plotted:

Location	Station	Elevation	Pressure height
		Feet	
East Coast Ranges:			
200 ft.	Falls City No. 2	440	Salem pressure minus 10 mb.
2,000 ft.	None (estimated)	--	--
West Cascade Range:			
200 ft.	Salem	196	Given
	Stayton	465	Salem pressure minus 10 mb.
2,000 ft.	Scotts Mill 9 SE	2,315	930 mb.
4,000 ft.	Government Camp	3,980	880 mb.

For west Cascade Range, 200 ft., the Salem surface temperature was used unless Stayton's temperature differed by 3°F. or more. In that event, the midpoint between the two temperatures was used. On days when Government Camp's northerly location made it appear unrepresentative of the west Cascade Range 4,000 ft. temperature, the 4,000-ft. station used was Santiam Pass (4,748 ft., 850 mb.).

A subjective warming or cooling (up to ± 3°C.) was made in the Salem raob curve to better simulate conditions over the Coast and Cascade Ranges for those days on which there appeared from upper air maps to be a strong east-west temperature gradient. The east or west side mixing levels changed accordingly.

Stability conditions. The smoke column from an active slash fire was assumed to have sufficient heat to lift it to the mixing level for the particular locality. The smoke was presumed to be above a stable layer over the smoke-sensitive area when all the following conditions existed:

1. Winds at dispersion level, as measured over Salem, blew in a direction that would move smoke toward the smoke sensitive area.

2. Mixing level (dispersion level) over the slash area exceeded 2,500 ft. and also exceeded the mixing level over Salem.

3. The layer between the Salem and slash area mixing levels was stable on the Salem sounding.

Adjusted fuel moisture. This simulated value of 1/2-inch fuel moisture sticks was determined from Spread Phase Tables of the National Fire Danger Rating System using 1600 P.s.t. Salem temperature, relative humidity, and 24-hour precipitation.

Buildup index. This index of cumulative drying in larger fuels was determined from the same tables as above.

Burning index. This index is based on spread index computed from the above-mentioned tables utilizing fuel moisture, buildup, and 1600 P.s.t. Salem wind plus additional weighting for fine fuel moisture in accordance with tables used in USDA Forest Service, Region 6.

Limits for adjusted fuel moisture. Limits used for adjusted fuel moisture are taken from the study by Morris (1966) of late summer and fall slash fires on six National Forests west of the Cascade divide. The values used (8 to 18.5 in spring and 8 to 25.5 in summer and fall) include a range covering all terrain aspects. Highest values apply to south-facing slopes and lowest to north-facing. Experience with spring burning on the Siuslaw National Forest, west of the Coast Ranges area considered here, indicates that fuel moistures as low as 5 percent may be desirable to assure an adequate burn at that season, in some situations.

Although the limit values were actually derived for the time of burning regardless of time of day, they have been applied here to the Salem 1600 P.s.t. adjusted fuel moisture. This may have eliminated some days as too dry when burning may have been possible at other times such as in the evening.

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